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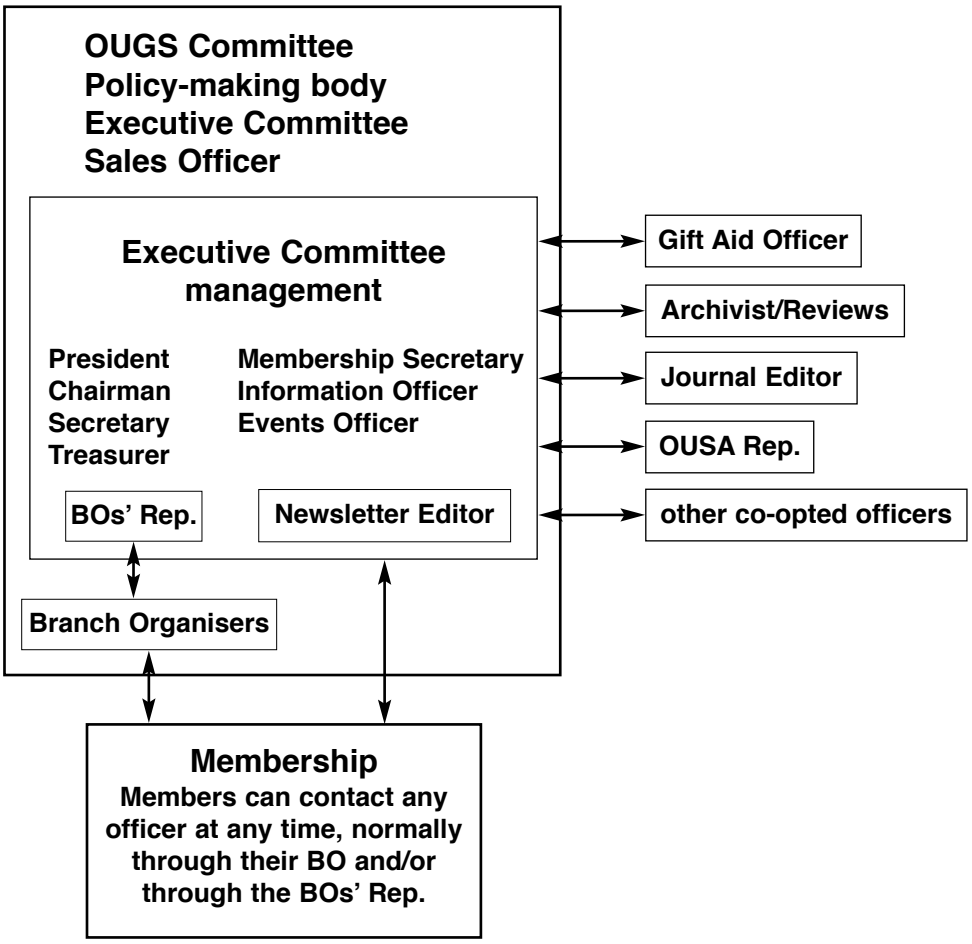

Editorial:

Dear readers,

The conversion to a full-colour journal appears to have been a success. Thank you to all readers who have sent comments in e-mails or who have spoken to me at the AGM or at the OUGS Symposium about the *Journal*. I very much appreciate your compliments and support.

And once again, I must express my gratitude for your patience in waitng for this *OUGSJ* issue. The reasons for the delay are partly explained at the end of this editorial.

The *OUGS Journal*, as I am sure you will agree, is an important and integral part of our society. Please do not feel shy about submitting a contribution for publication. If you have been on an inspiring field trip in which the geology has been especially interesting and new to *you*, why not share your enthusiasm and new knowledge with your fellow members. With your trip leader and trip companions, why not write-up the field notes to summarise the geology with details of the locations you visited, a graphic log, a table or chart to explain the geology of the region and locations, and photographs and sketches?

Your Editor is grateful for all submissions.

This issue includes the annual Geoff Brown Memorial Lecture, presented this year at the OUGS AGM 2011 in Myerscough College, Bilsborrow, Preston. The lecture was presented by Dr John Stevenson of the School of GeoSciences, The University of Edinburgh, on the monitoring of Mexico's most active volcano — Volcán de Colima, in the State of Colima.

Central Mexico has been a region of violent, active volcanism throughout its geological and historical existence. Volcanism became an intricate part of ancient Mesoamerican culture and mythology, even in some cases altering the course of cultural development. In modern times, it is therefore literally vital to the people living in the vicinity of still-active volcanoes such as Volcán de Colima that geologists continue to develop methods to monitor and try to predict future eruptions, so that geohazard procedures can be improved and provide essential warning.

The remaining papers have all been written by some of your fellow OUGS members. These papers record their personal, special geological interests, such as Chris Popham's (OUGS South-West Branch) passion for industrial geology and the mining industry of south-western Britain.

There is another interesting paper by John Downes on his continued investigations and summaries of the geologic regions of Wales. Duncan Woodcock has sent us two more reports in his contiued visits and researches into the geology of the Canary Islands. And Elisabeth d'Eyrames (Branch Organiser, Mainland Europe Branch) and her colleagues have written-up their energetic field trip to the Bavarian-Bohemian Geopark, sharing with us their geological enthusiasm.

The OUGS Symposium 2010 in Swansea was a great success in presenting attending OUGS delegates with a weekend of lectures on the theme 'Cutting-edge research from local universities'. The energetic members of the OUGS Symposium Committee for the Swansea Symposium were, unfortunately, unsuccessful in their requests and attempts to persuade the speakers to write-up their papers for publication in the *OUGS Journal.* As Editor of the *Journal*, I also made several approaches to each speaker, but was, sadly, equally unsuccessful.

Although this is regrettable, we all understand the numerous commitments of our academic geological colleagues. The Swansea speakers were unable to write-up their papers for publication for a variety of reasons. Therefore, for the benefit of the Symposium delegates and for those OUGS members who could not attend the Symposium, the abstracts are printed in this volume, in keeping with OUGS's new policy regarding Symposium lecture publication.

— David M. Jones, *OUGS Journal* Editor

Erratum

OUGS Journal ***31*** *(1–2), page 31*

In the article 'A predecessor of Darwin? The surgeon William Lawrence' by Philip Clark, for the portrait on this page, proper acknowledgement was unfortunately left off the caption. The full caption should read:

'William Lawrence by Charles Turner, ARA, before 1839 (© The Royal College of Surgeons of England, with permission).'

The Editor apologises for this omission.

OUGS Geoff Brown Memorial Lecture — 16 April 2011: Monitoring Volcán de Colima: Mexico's most active volcano

Dr John A. Stevenson

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http://www.geos.ed.ac.uk/homes/jsteven5
http://all-geo.org/volcan01010

Figure 1 A typical eruption of Volcán de Colima from early 2006, viewed from the library of the Colima University.

Introduction

Background

From January 2006 to August 2007 I worked as a postdoctoral researcher at the Centro de Intercambio e Investigación en Volcanologia (CIIV) at the Universidad de Colima, Mexico (Fig. 1). Volcán de Colima, 30km from the city and Mexico's most active, had recently seen a period of increased activity, and my role was to help with the installation of new monitoring equipment and the development of new monitoring techniques at the volcano. I also helped co-ordinate and train the volunteer students that carried out much of the science in the group.

This article outlines some of the monitoring methods, both old and new, that are in use at the volcano, and presents some of their resulting data. Using examples from Colima, it also illustrates the most common hazards found at volcanoes worldwide.

Volcán de Colima

Volcán de Colima is an andesitic stratovolcano located 100km from Mexico's Pacific coast, and about 350km west of Mexico city. This is the western end of the Trans-Mexican Volcanic Belt that includes Popocatapetl and Pico de Orizaba. It sits within a N–S trending graben on the state boundary between Colima and Jalisco states. The Colima volcanic complex consists of a series of older, extinct edifices that get younger towards the south. The 4,200m Nevado de Colima ('Snowy') is located 5km north of the currently active 3,800m peak, known locally as Fuego ('Fire').

The volcano has had many periods of activity since pre-Hispanic times and has been continuously active for over a decade. It produced lava flows and domes (effusive eruptions) in 1998–9, 2001–3 and 2004, and has been exploding 3–12 times per day since 2003. These explosions are generally small, discrete, vulcanian-type events, which produce ash clouds that rise just a few kilometers above the vent. However, the volcano has also produced much bigger eruptions in the past, with Plinian and sub-Plinian eruptions in 1576, 1606, 1690, 1818 and 1913.

In view of these larger, past events, the Mexican government made extra funds available for monitoring in 2005, following a series of larger explosions that also produced pyroclastic flows. This money was distributed among the groups involved in monitoring, which include the Observatorio Volcanologico at the Universidad de Colima, the Colima Seismic Network (RESCO), the civil protection agencies of both Colima and Jalisco states, and the CIIV in the Facultad de Ciencias of the Universidad de Colima (of which I was part).

Structure of article

This article describes the monitoring equipment and the data that it produces, grouped by location on the volcano. At each location, the evidence for the corresponding volcanic hazards is also described. The three locations are: (1) the volcano observatory building run by the civil protection agency of Jalisco, located near the summit of Nevado de Colima, (2) El Playón, an area of flat ground near the upper cone of the volcano, and (3) the barrancas (ravines) that are carved though the forest into the flanks of the volcano (Fig. 2).

Figure 2 Google Earth view of Volcán de Colima showing the main areas for fieldwork. The extinct Nevado de Colima is visible to the north. Lava flows are clearly visible on the flanks of the volcano.

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Nevado de Colima: monitoring

The Observatorio Volcanologico near the summit of Nevado de Colima is a permanently manned base run by the Civil Protection Agency of Jalisco state. Located at 4,000m altitude, and *c.* 5km from the crater of Volcán de Colima, it provides an excellent platform from which to view the ongoing activity. During the period that I worked there, staff or students from the CIIV would travel up to Nevado about once a fortnight, and spend 24–48hrs at the observatory collecting data.

Infrared camera

My arrival in Colima coincided with arrival of a VarioCAM infrared camera, and my main project was to develop a method for collecting and analysing the data that it produced. The camera measures the apparent temperature in each pixel of each image and makes it possible, for example, to measure the temperatures of explosions. The apparent temperature is lower than the true temperature because at a distance of 5km, each pixel samples a 10m × 10m area on the ground, which contains both hot and cold regions. As a monitoring tool, we found it useful for longer-term measurement of changes in the temperature of fumaroles on the crater rim (Fig. 3).

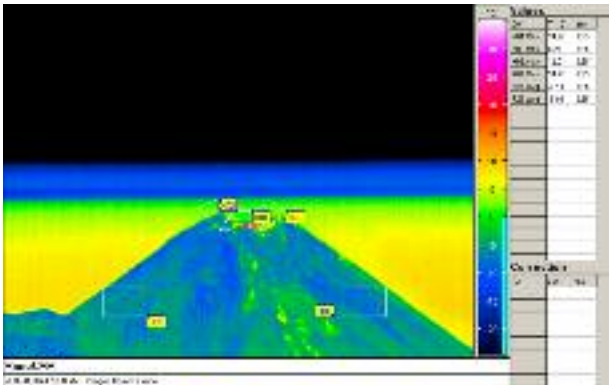


Figure 3 Image in infrared of a volvanic explosion.

A fumarole is an area where hot gases escape from the volcano. During trips to Nevado we recorded an image every five seconds, then from each image we extracted the temperature in each from three different fumaroles on the crater rim, and two non-fumarole areas that could be used as a background measurement. The resulting sequence of 10,000 temperature measurements was filtered to remove data from daytime (which is affected by solar heating), or when there were rapid fluctuations (caused by passing clouds) and corrected for atmospheric effects. This gave an average temperature for the fumarole for each visit, which could then be plotted to reveal longer-term trends (Fig. 4).

Figure 4 shows the changing apparent temperatures at the Central, East and West fumaroles between January 2006 and September 2007. The East Flank and West Flank data show background temperatures, and a clear seasonal-trend is visible. The central fumarole temperature shows a decline, from 40° to 20°C, on which the seasonal trend is superimposed. The East and West fumaroles show a similar trend. This cooling trend is consistent with the gradual decline in the size, frequency and ash-content of the explosions that had been observed since late 2005.

COSPEC and FlySPEC

Measurements of sulphur dioxide (SO_2) release were also made from the Nevado observatory. COSPEC and FlySPEC are two models of ultraviolet spectrometer that use the absorbance of specific wavelengths of sunlight by SO_2 to estimate the concentration of the gas in the air. When combined with information on the wind speed and direction, the SO_2 flux from the volcano can be estimated. Fresh magma rising beneath a volcano degasses as it rises and as it cools, so an increase in SO_2 flux could indicate new magma arriving beneath the volcano. Estimates of the gas released in each explosion were small (<10 tonnes) and the uncertainty was considerable, so no long-term trends could be identified. By contrast, the flux jumped to 1600 tonnes per day prior to the 1998 effusive eruption, demonstrating that important changes may nevertheless still be identifiable.

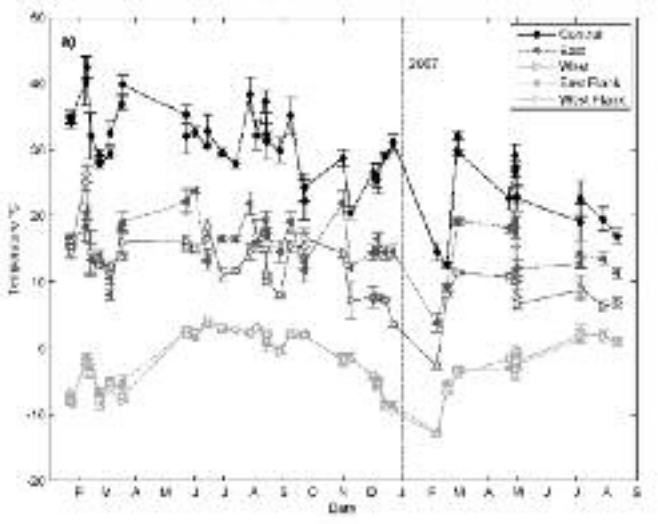
Nevado de Colima: hazards

Explosive eruptions

During my time in Colima, the volcano was exploding between three and twelve times per day. The small plumes that the explosions produced deposited ash on the immediate flanks of the cone, but had little effect at greater distances. During 2005, the explosions were bigger and the plumes would rise much higher. The people of Colima would awaken to find everything dusted with a fine coat of ash. In the forests of Nevado is evidence for even bigger eruptions. Layer upon layer, centimetres to tens of centimetres thick, containing not just ash, but also popcorn-like pumice, are testament to much larger explosions in the past. These explosions were sub-Plinian and Plinian in size, and would have produced plumes that reached over 20km above the crater.

The hazard for such explosions depends on the direction of the wind. During the plinian eruption of 1913, the wind blew the cloud towards Ciudad Guzman, 25km to the NE. A layer of more than 150mm of tephra was deposited on houses in the town, causing many of their roofs to collapse. In Colima, there are only really two seasons: *secas* (the dry season, October to May) and *lluvias* (the rainy season, June to September). During the dry season, the wind generally blows towards the east; in the wet season

Figure 4 Trends in apparent fumarole temperatures as measured by infrared camera. The true temperatures are much higher. The East Flank and West Flank data represent non-volcanic changes and show a clear seasonal trend. The fumaroles show an overall decline through 2006 and 2007.



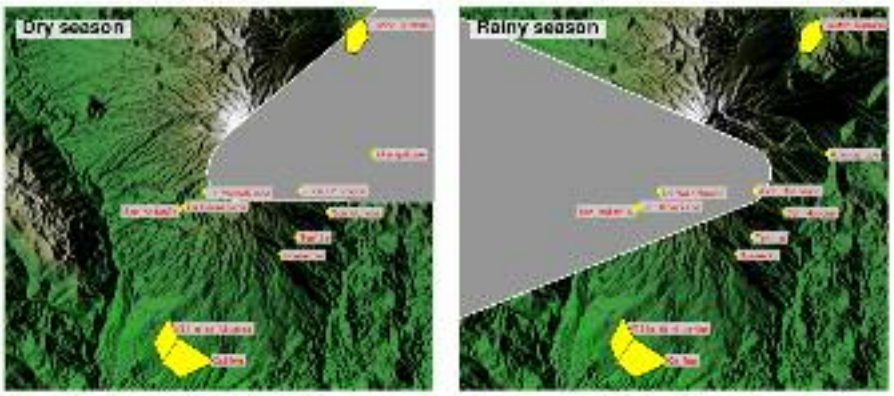


Figure 5 Combined dry and wet ash distribution: Areas affected by ash fall based on season of eruption. These are general patterns based on average wind directions for the dry and wet seasons, and in reality significant ash fall could be experienced at locations in any direction.

it blows the other way. The hazard map, showing the areas most likely to receive significant tephra fall during an explosive eruption reflects this (Fig. 5).

El Playón: monitoring

The Playón is a relatively flat area lying to the north of the foot of the main cone of Volcán de Colima. It was completely resurfaced by the pyroclastic flows of 1913 with unconsolidated scoria and ash and now has only a sparse cover of pine trees. El Playón translates as 'The Big Beach', reflecting the sandy expanse.

Seismic monitoring

There are a number of seismometers on the flanks of the volcano that are accessed via the Playón. Seismic monitoring is very important at Colima and is carried out by the Colima Seismic Network (RESCO). Figure 6 shows a seismogram from 2005. The lines grow from left to right, taking 15 minutes for a complete line before beginning another beneath. The image shows 24 hours worth of data, from September 16, 2005, and the large explosive eruption at 10:47hrs is clear. The many small events that are extremely common before the explosion and less-so afterwards are known locally as *pulgas* ('fleas'). These events were associated with all the big explosions of 2005.

The analysis performed in CIIV was unsophisticated compared to the work in volcano observatories around the world, but still produced useful results. The 'fleas' were counted directly from the seismograms using digitising software. Clic king every flea of every day through more than two years of data enables us to resolve the trends in activity. The figure shows a plot of five-day running average flea counts; the black triangles represent explosions that produced pyroclastic flows. The period of high activity in 2005 is clear. The long tail of lower activity from 2006 onward is consistent with observations of the explosions and with the results of fumarole monitoring.

El Playón: hazards

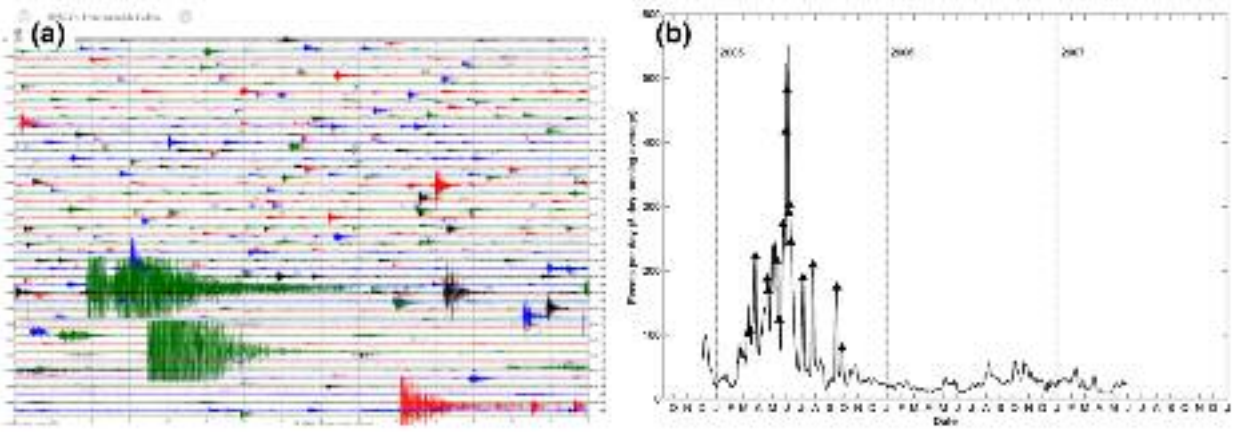
Lava bombs

The soft surface of the Playón makes it ideal for studying the formation of bombs (also known as ballistic clasts) during explosive eruptions (Fig. 7, *overleaf*). These were blasted from the volcano during large explosions in 1998, 2001 and 2005. Upon impact, they smashed apart and generated large craters. Some of the bombs were >1m in diameter, and the craters were up to 8m wide. Thousands were measured. Sometimes, where they fell through trees, their trajectory could be worked out from the lines of snapped-off branches. They fell at angles of >70 degrees, and calculations of their range and trajectory show that they must have been ejected from the volcano at supersonic velocities (>200ms^{-1}). The maximum range of the ballistic clasts is *c.* 5km, so they do not present a threat to any settlements.

Lava flows

The most recent lava flow produced by Volcán de Colima was formed in late 2004 and ran down the north flank of the volcano to the Playón. It is an andesitic block lava typical of the volcano, with a thickness of >20m. Lava flows from the volcano have a range of 3.5–8km. They are strongly controlled by gravity, so tend to be confined to the *barrancas* (narrow ravines). As they advance at <100m per day, they present little direct threat to people, but if parts of them collapse on steep ground they can produced more dangerous pyroclastic flows.

Figure 6 Seismogram and 'flea' counts: Sseismic data from Volcán de Colima. The data were collected by RESCO (http://resco.ucol.mx): (a) graph of seismic activity from 16 September 2005 showing 'fleas' and explosions; (b) fleas per day for 2005–2007. The black triangles represent explosions that produced pyroclastic flows. Activity has been relatively low since late 2005.



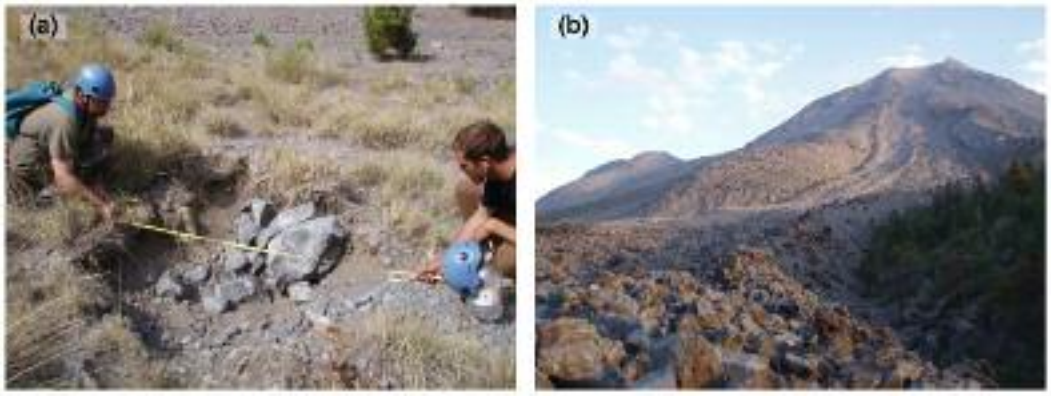


Figure 7 Lava bombs and lava flow, features of El Playón: (a) lava bombs form craters in the soft ground where they land; (b) the blocky surface of the October 2004 lava flow.

Since 2007 Volcán de Colima has been producing lava, and a lava dome has gradually filled the summit crater. The dome is growing extremely slowly, with an extrusion rate of just $0.01 m^3 s^{-1}$ (compared to $5–10 m^3 s^{-1}$ at other dome-forming eruptions, such as Montserrat). At the time of writing (May 2011), small rockfalls have been recorded where the crater is beginning to overflow, but things continue to change very slowly.

In December 2010, heat from the lava dome was detected for the first time in four years by satellite remote sensing. Figure 8 shows data from the MODIS instrument for the period 2002–7. The data are freely available, and by downloading and plotting them, it was another opportunity to put the activity of the volcano in a longer-term context. The figure shows the many thermal alerts during the effusive (lava-producing) eruptions of 2001–3 and 2004. It also picked up signals in 2005. These may be explosions that coincided with the satellite passing overhead, or are fresh pyroclastic flow deposits, or just increased heat flow from the crater. Again, in line with the fumaroles and the seismic data, things have been relatively cool since 2006.

Las Barrancas: monitoring

The *barrancas* are a series of deep, rocky ravines that radiate from the summit cone of the volcano. They cut through the thick forest, providing a relatively easy pathway up to the volcano from lower on the flanks. They are dry for most of the year, except for short periods during the rainy season when they are a pathway for lahars. At times, they have also been pathways for lava flows and pyroclastic flows.

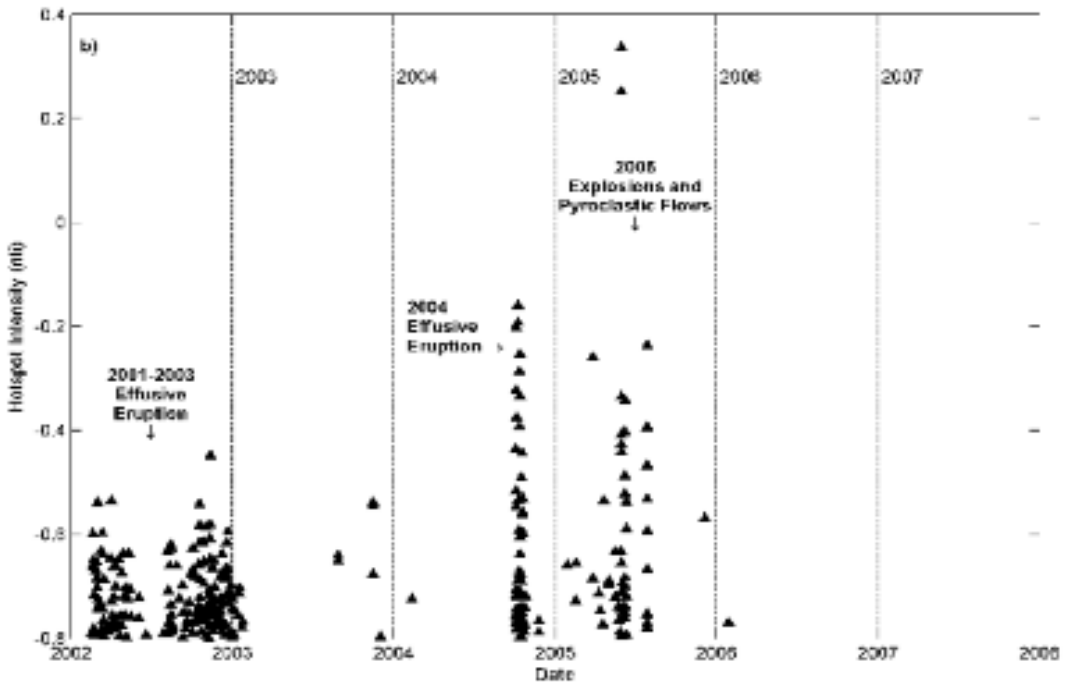
Installing monitoring stations

During February 2007 we installed a new monitoring station on the south flank of the volcano, near Barranca Montegrande. As well as the instruments themselves, ancillary equipment is needed for power and data transfer. Thus, the station consisted of eight 90W solar panels connected through a charge regulator to a bank of four car batteries. This provided power to a datalogger, which took readings from the sensors. Data were sent directly to the university via radio modem, through an antenna that we erected. The whole system was buried in shallow a bunker, with a corrugated steel roof to protect it from ballistic clasts and a padlock to protect it from people that wanted new car batteries.

Infrasound and thermal sensors

The new station was set up to monitor infrasound waves and plume temperatures. Infrasound waves are sound waves with a frequency of 0.5–15Hz. This is too low for us to hear, but is produced by the volcano during explosions. Small pressure transducers were installed that measured changes in atmospheric pressure as the waves passed. Infrasound monitoring is a relatively new tool in volcano monitoring, and can be used in many of the same ways as seismic techniques; for example, a network of sensors can triangulate the source of an explosion and give an indication of its size.

Figure 8 MODIS monitoring data: thermal alerts at Colima from the satellite-based MODIS instrument. Alerts coincide with both lava-producing and explosive activity. None were detected between early 2006 and late 2010 (not shown), despite the slow growth of a lava dome within the crater.



The Open University Geological Society's Geoff Brown fund was kind enough to donate two non-contact thermometers. These tools have been used in other volcanoes to measure the temperature of lava lakes and crater rocks. Ours were positioned pointing at the sky above the crater, so that during an eruption the plume would rise into their field of view and we could measure its temperature.

Preliminary results

Before installation of the sensors, the number of explosions at the volcano each day was estimated from the seismic record. However, sometimes a seismic signal would not have any associated explosion, or a large explosion would have a relatively small seismic signal. The new sensors enable us to check events, even if no-one actually witnessed them. Unfortunately, this system cannot be used during the rainy season, when clouds obscure the crater and thunderstorms produce natural infrasound.

An example event is shown in Figure 9. Note the delay between the seismic data and the infrasound. This is because seismic waves travel through the ground at *c.* 2km s^{-1}, compared to sound travelling through the air at ~300m s^{-1}. The plume is clearly detected by the Geoff Brown thermal sensors, confirming that the seismic signal did indeed correspond to an explosion.

Las Barrancas: hazards

Pyroclastic flows

Pyroclastic flows, also known as pyroclastic density currents, are fast-moving mixtures of hot rock, ash and gas that are produced when part of a lava dome spalls off, or when an eruption column loses buoyancy and collapses. They have velocities of >100km hr^{-1} and temperatures of up to 600°C. The large explosions of 2005 produced pyroclastic flows that reached up to 5.4km from the crater. They were funnelled down the *barrancas*, flowing as two parts: a dense, clattering mixture of hot boulders and gravel and a more dilute cloud of ash and gas (sometimes called a pyroclastic surge) that rose from surface and was less-confined by gravity. This behaviour is clear from videos available online (e.g. http://www.metacafe.com/watch/119241/big_in_japan/) and is reflected in the deposits. The figure shows Barranca San Antonio, filled with coarse debris from the basal part of the flow, while the leaves of the trees record how the surge cloud scorched them.

The pyroclastic flows of the 1913 eruption were much bigger, reaching up to 13km from the crater. A repeat of this eruption would reach a number of settlements, and in fact some of the houses in La Yerbabuena have been built using clasts of 1913 scoria. Figure 10 *(overleaf)* shows the areas that would be affected by pyrclastic flows in a 1913-type scenario. In 1998, when the current volcanic unrest began, the government resettled most of the population of La Yerbabuena in another village farther from the volcano. This was unpopular and controversial, as the people were moved far from the fields that are their livelihood, and especially because a number of ranches and other buildings belonging to wealthy or powerful individuals were not relocated. However, the fact remains that when the next Plinian eruption occurs, these areas will probably be destroyed and anyone in them will be killed.

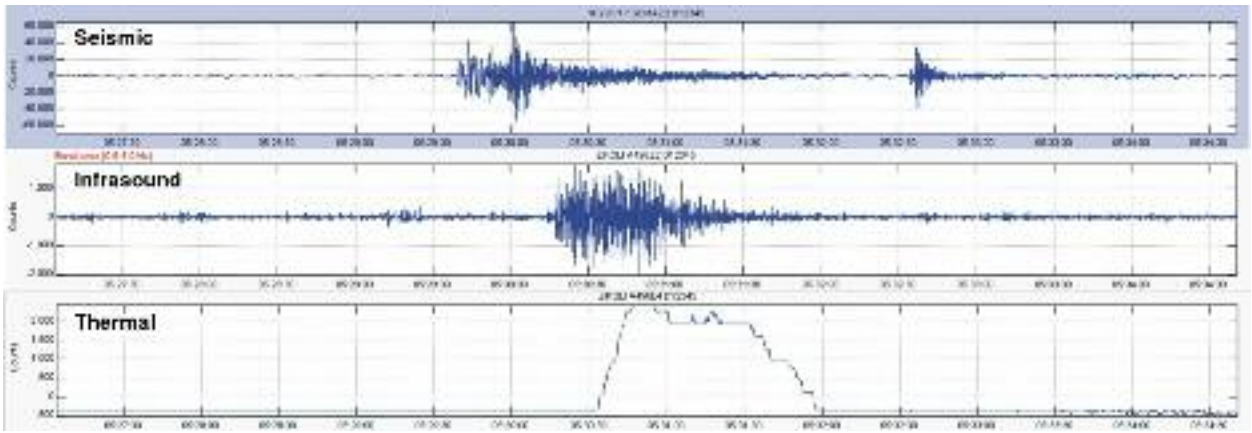
Lahars

Lahar is an Indonesian word meaning 'volcanic mud flow'. At Colima they are common during the wet season, when heavy rainfall remobilises the loose unconsolidated debris on the flanks of the volcano. The 2006 season saw an increase in the size and frequency of events as the 2005 pyroclastic flow deposits presented a ready supply of material. The lahars have a range of 15–20km and travel down the barrancas at velocities of >50km hr^{-1}. High on the volcano's flanks, small lahars occur almost every time that it rains. Some video footage of these is available online at http://all-geo.org/volcan01010/colima-lahar-videos link to be confirmed. Figure 11 *(overleaf)* shows construction of a levee at the mouth of Barranca Montegrande to protect a line of electricity pylons. Larger events can reach inhabited areas, prompting evacuations in 2007, destroying a house in La Becerrera in 2000, and resulting in over 20 fatalities in Atenquique in 1955.

A further-reaching hazard?

The effects of ash fall, lava and pyroclastic flows, lahars and bombs are all very apparent at Volcán de Colima. However, there is another phenomenon that presents a much greater hazard. It is less frequent, so the evidence is more subtle, but it is unequivocal. Firstly, the Playón is bounded by a 300m-tall scarp of assorted lava, volcanic debris and intrusions that opens

Figure 9 Infrasound and thermal results: seismic, infrasound and thermal sensor data for a typical explosion. The event was detected by all three systems. The data enable us to confirm the emission of hot gas and ash associated with the seismic signal, even if the event had no human witnesses.



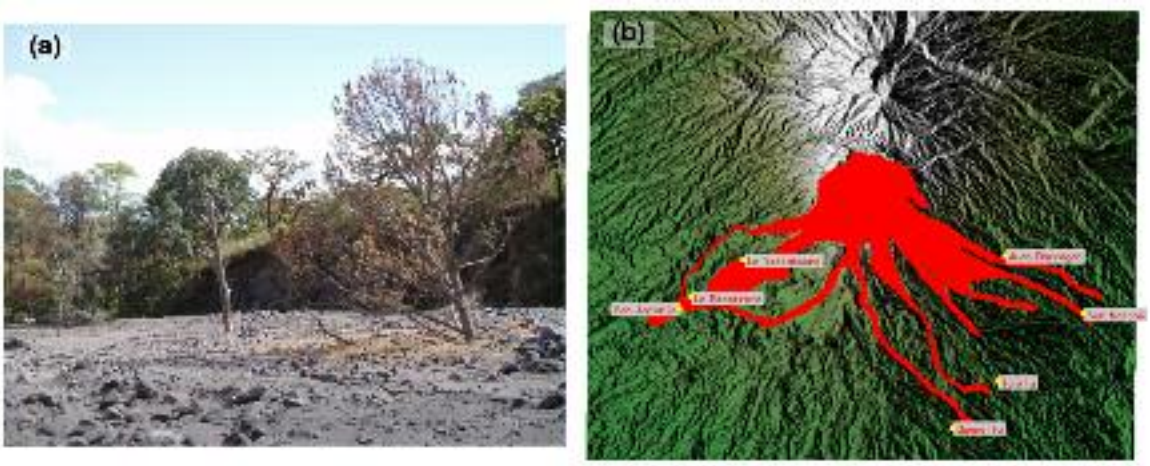


Figure 10 Pyroclastic flow deposits and hazard at Volcán de Colima: (a) pyroclastic flow deposits fill the barranca and partially bury trees — the scorched leaves are evidence for the less-dense pyroclastic surge; (b) The pyroclastic flow hazard zone, based on a 1912-sized eruption, extends up to 15km from the volcano — this flow area contains a number of settlements, including La Yerbabuena and La Becerrera.

to the south (Fig. 12). Secondly, the topography to the south of La Becerrera comprises a series of 100m-tall hummocks, each of which contains similar volcanic lithologies to the Playón wall. However, the rocks are fractured and shattered. Thirdly, these shattered rocks are found throughout the Colima graben, including within the city itself. Initially solid lava has been pulverised into a jigsaw-fit breccia that crumbles to the touch.

These features are the product of a debris avalanche, where the whole flank of a volcano collapses. The most recent example of this was the May 1980 eruption of Mt St Helens (see it at http://www.youtube.com/watch?v=bgRnVhbfIKQ). Debris avalanches can travel at velocities of 240km hr^{-1}, with a range of 30–100km, transporting large chunks of volcano (>100m diameter) with them. A large debris avalanche at Volcán de Colima would destroy every settlement within the graben to the south of the volcano, including Colima and Villa de Alvarez, potentially killing up to 250,000 people. Fortunately, studies combining stratigraphic work, boreholes and ^{14}C data have shown that they are rare, with the most recent taking place *c.* 3.6ka.

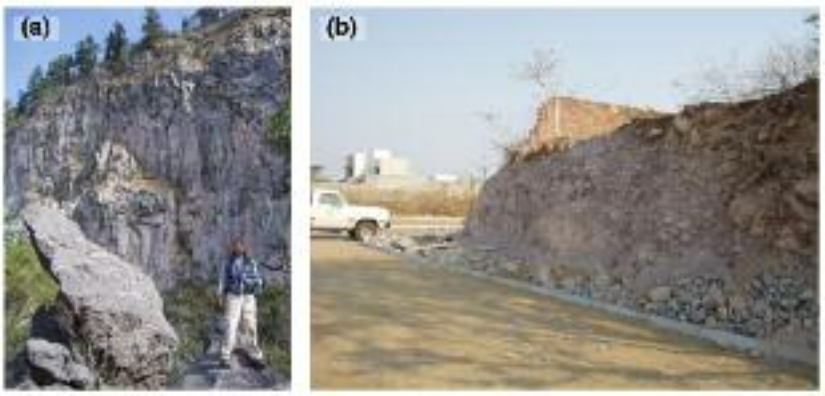
Concluding remarks

Given all the hazards that the volcano presents, you may wonder why people live in Colima? In reality, the volcano, puffing away quietly from day to day, represents only a very localised threat to very specific areas, e.g. the *barrancas*. The hazards are summarised in a map published by the Volcano Observatory and available at http://www.ucol.mx/volcan/imagenes/mapa.gif. As in the UK, the greatest danger to the average Colimense is probably the road system, and they also have earthquakes (magnitude 7.8 in 2003), hurricanes, poisonous snakes and spiders to deal with. For some of the poorest citizens, just earning enough money to eat is a challenge in the face of escalating maize prices. Furthermore, the volcano has been part of the culture in Colima since prehispanic times and is a symbol of the state throughout Mexico. It is also one of their greatest tourist attractions.

In summary, Volcán de Colima has been in a state of constant activity since 1998, and currently erupts every day. Generally, the intensity of this activity has been in decline since the large

Figure 11 Excavation of lahar channel: construction of an earth dam at the mouth of Barranca Montegrande. The area is a shallow fan of loose debris washed from the flanks of the volcano by repeated lahars.

Figure 12 Playón wall and smashed rock in town. Evidence for a further-reaching hazard: (a) the Playón wall is a steep scarp cut through volcanic rocks including intrusions, lava flows and pyroclastic deposits; (b) the town of Colima is built upon crumbly breccias that are the pulverised remains of volcanic rocks such as lava flows.



explosions of 2005, but, little by little, a lava dome is growing in the crater and will eventually overspill. The changing activity is reflected in fumarole temperatures, seismic event counts and satellite thermal data. New studies of gas release, infrasound and plume ascent rate, using equipment provided by the Geoff Brown Fund, will give new insight into volcanic processes at Colima. Hopefully this increased understanding will help scientists anticipate the next Plinian eruption, which, when it comes, will destroy settlements and disperse ash widely.

CIIV and volunteering

One of the highlights of my time in Colima was working with the volunteers of the Centro de Intercambio e Investigación en Volcanologia. This was set up by Dr Nick Varley in 2004, within the Faculty of Science at Colima University, and provides opportunities for volunteers to gain experience working on an active volcano. I met more than 50 students, from a variety of backgrounds and from diverse countries, such as the UK, the USA, Canada, Mexico, Germany, France, Italy, Spain and Israel. They helped with collection of thermal data, installation of equipment and processing of seismic and other data.

Volunteers do not need a completed geology qualification, just basic computer-literacy, an ability to spend days out hiking, plenty of enthusiasm and at least a month to spare. There is no funding available, but living in Colima is not expensive (<£500 per month) and it is a great experience.

For more information, visit http://www.ucol.mx/ciiv.

Book review

Bennison, George M., Olver, Paul A., and Moseley, Keith A. 2011 *An Introduction to Geological Structures and Maps* (8 edn). London: Hodder Education (ISBN 978-1-44411-212-2; paperback, 168pp; £21.99)

This book has been billed as "one of the great survivors of geological textbooks", although the first edition in 1963 was sadly not published quite in time for my school geology mapwork lessons. I really would have welcomed it then, as we did our 'map a week' for two years, all to a high degree of precision as regards dip angles, vertical exaggeration, structure contours etc. When I look back at my old school textbooks now, and even at my old OU texts, they look like something out of the Cryptozoic! Some *OUGS Journal* readers will know one or more of the authors: Paul Olver is active in geology in the Hereford and Worcester area and Keith Moseley is a colleague of mine who tutors the OU Level 2 Astronomy and Planetary Science course in Wales and the South West. The doyen of the three though is George Bennison, who Keith tells me was teaching geology at Aberdeen University in the 1930s! So, lots of experience between them there to bring to the subject.

Geological Maps and Structures was already updated considerably in the 7th edition with field photographs and extra problem maps, but this new edition is illustrated in full colour, uses a BGS map to show mapping of a real area, and includes a new glossary. Several aspects of this new edition should be particularly welcome: the introductory material has been reworked to help you to grasp those difficult 3D concepts more easily, the text on outcrop patterns has also been expanded to aid 3D visualisation — so often a stumbling block — and 10 more maps that don't use structure contours are included, making 45 problem maps in all. There are 11 useful little models, which can be cut out and put together — some of you may remember the ones we had for S236? There is great emphasis on constructing cross sections — something that is key to understanding the underlying structure of a map area — which ties in to photos and line drawings of quarry faces that again helps the 3D aspect of the work.

What this book isn't, is just more map problems of the type you've encountered in your OU course … a fold, a fault, a dyke/sill/lava flow, a pluton and an unconformity arranged in as many ways as possible … although there are some of those. What it is, is a book that, worked through carefully, will give you a thorough understanding of geological maps and enable you to 'read' a geology map and visualise the subsurface structure for yourself. Several OUGS branches have bought a copy for their library as well as the copy held in our main library so, if mapwork isn't your strong point and you want to have a go at improving it, borrow a copy and see what you can do!

— Linda Fowler BA(Hons), OU graduate and S276 Geology Tutor (and module team deputy chair)

Book review

Foulger, Gillian R. 2010 *Plates vs Plumes: A Geological Controversy*. Oxford: Wiley-Blackwell (ISBN: 978-1-44433-679-5; hardback, 328pp; £75)

About 90% of the Earth's volcanism occurs at mid-ocean ridges and subduction zones, where the cause of the activity is fairly well understood. This book is concerned with the controversy surrounding the cause of the remaining 10%, usually known as intra-plate volcanism. The cause of intra-plate volcanism is traditionally ascribed to the action of deep mantle plumes, possibly originating at the core–mantle boundary. In recent years an alternative hypothesis, the 'Plate hypothesis', has suggested that intra-plate volcanism is the result of shallow mantle processes that are related to plate behaviour. The author of the book is a champion of the Plate hypothesis and manages the website www.mantleplumes.org. Some readers may remember Prof. Foulger's presentation to the OUGS Symposium in 2007 (see OUGSJ 28(2), 16–21).

The first chapter presents an overview of both hypotheses and an introduction to the rest of the book. The following six chapters contain the 'meat' of the book, where each chapter deals with the debate from one particular viewpoint and is structured in a similar way. Chapter 5, for example, takes a seismological viewpoint. The introduction to this chapter reviews the various seismological techniques with a particular emphasis on the inherent assumptions and limitations: this makes the subsequent chapter contents accessible to the non-specialist. A detailed review of the seismological evidence for the two hypotheses is then presented and discussed. The final chapter of the book then pulls these various threads together and reviews the 'plates vs plumes' debate from a philosophical viewpoint, considering such issues as to what extent a hypothesis can be continually modified and adapted to fit observations.

The book is well produced and has a comprehensive index and set of references to the literature. Unfortunately some of the black and white images are completely baffling until one examines the corresponding image in the colour plate section, where identical grey shades in the former images are often different colours.

This book is a long overdue monograph of the 'plates vs plumes' debate, as it pulls together much disparate material into a coherent exposition. It is highly recommended to all OUGS members, who could consider reading the first and last chapters, together with one or two of the main chapters, as a minimum.

— Duncan Woodcock, MA, BSc Hons (Open)

Tin extraction on Dartmoor

Chris Popham (OUGS South-West)

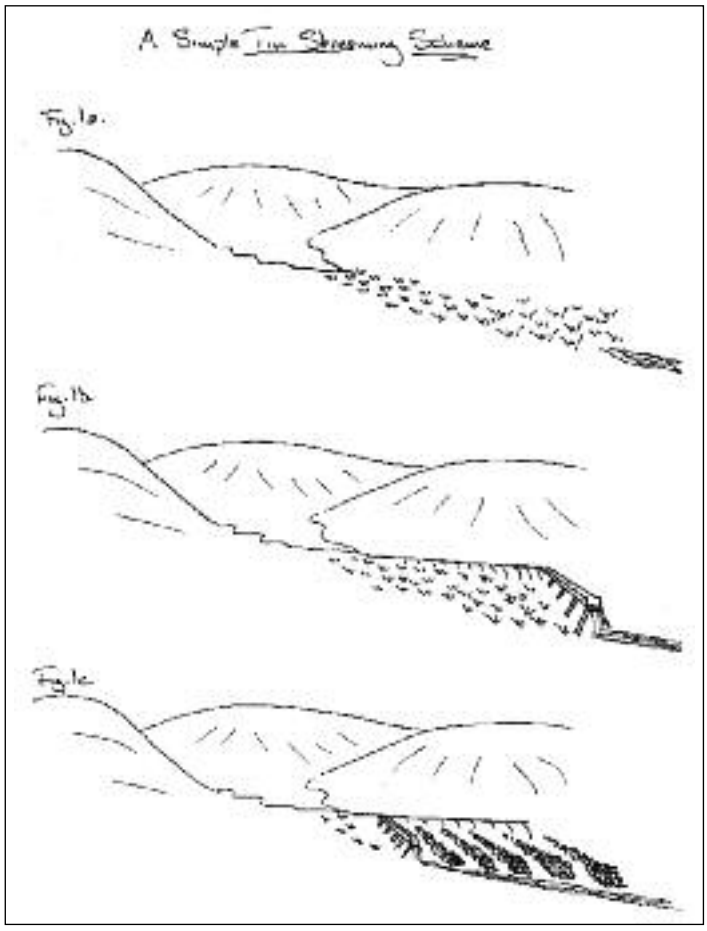
Introduction

The principal sources of tin for the ancient Greeks, Persians and Egyptians came from Anatolia (modern Turkey). [There were, however, other sources of tin in the Mediterranean world and beyond. One reason for the growth of Greek colonies along the Mediterranean coast of Gaul may have been that following the Battle of Alalia *c.* 537 BCE (in which the Greeks defeated an alliance of the Carthaginians and the Etruscans), the Carthaginians effectively still kept control of the southern Iberian (modern Spain and Portugal) ports and prevented the Greeks from obtaining access, not only to the mineral wealth of Tartessos (Ibero-Phoenician 'kingdom' of the southern Atlantic coast of Spain, whose principal port was the Phoenician colony and port of Gadir – Cádiz), but also to the Atlantic trading systems beyond where much of the tin for the Greek market had formerly been obtained (Cunliffe 1994, 339) — this additional material added by Editor, with author's agreement.]

When Mediterranean traders learned of deposits in Cornwall, so precious was this resource that they kept the secret until 350 BCE. Anecdotal accounts suggest that Phoenician traders may have been referred to the south-west of England as 'The Cassiterides' or 'Tin Isles', but show their location as the Isles of Scilly, which has no tin. [The source of this is a vague reference in the descriptions of the voyages of two Carthaginian brothers, Himilco and Hanno, *c.* 425 BCE beyond the Pillars of Hercules (Straits of Gibralter). Hanno sailed south along north-west Africa, while Himilco sailed in another, but uncertain, direction. Later Greek and Roman writers undoubtedly copied from the earlier description of the Himilco and Hanno voyages. Recent scholarly interpretation considers the original text descriptions of the nature of and location for the Cassiterides to be too vague to locate them/it exactly. It is doubtful that Hamilco sailed north, at least not as far as Cornwall or Ireland, but that he more likely sailed west, found little and returned. The description of Cassiterides in these texts can be interpreted to be all sorts of places in western Europe north of Iberia (Cunliffe 2008, 6 and 346; Bourne 2011) — this additional material added by Editor, with author's agreement.]

What seems certain, however, is that one of the main aims of the Roman conquest in 43 CE was to gain control of the source British tin. The Romans prized tin greatly as a tarnish-resistant coating for utensils made of other metals like copper and because it was easy to work into utensils.

Figure 1 A simple tin streaming scheme (sketch by Chris Popham).



Medieval tinning

The earliest actual written record of tin production on Dartmoor is medieval, dating from the mid-12th century. However, even at that time tinning was a big business, not only for the metal but also because 'Tinners' were exempted from duty to King and Country and from some taxes. The Tinners established their own set of laws, and accounts of the earliest Stannary Parliament date from the mid-10th century. These laws set the dues on the metal payable to the Crown and the criteria for assays for quality. In 1195 a stannary court and gaol were built at Lydford and from 1198 there is a record of the first Stannary Parliament to be held on Crockern Tor, just outside Princetown.

In the 13th century The Crown in London tried to take direct control of the south-west tin industry. Concerned that they would lose their freedom and livelihood, the miners threatened revolt and began a march on London. Faced with the prospect of an army of 11,000 hardened miners arriving in the capital The Crown backed down. Thereafter, in the early 14th century Ashburton, Chagford, Tavistock and later Plympton were designated as the stannary towns where dues were collected and where assaying and second smelting were carried out.

Up until the 17th century the majority of tin works were of the streaming type, working alluvial deposits where cassiterite had collected in depressions in the landscape (Fig. 1a). Most of this was dissociated mineral crystals, but cassiterite-rich pebbles or 'shode' could also be found.

The first step in the streaming process was to divert the watercourse (Fig. 1b). A raised 'launder' was set up to direct the flow of water across the site. The alluvial ground was dug up and loaded into the launder. Large stones were set aside, small particles of rock and sand were washed away by the water and the denser cassiterite collected behind small battens, called 'riffles', fixed across the bottom of the launder at right angles to the flow.

Once all the ground within easy reach had been worked, the launder was re-sited farther up the stream works and the process continued until either the deposit was worked out or there was no

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Figure 2 Foxtor streaming works.

further demand. This left the characteristic Dartmoor feature of wide shallow valleys with linear banks of waste rock enclosed by escarpments (Figs 1c and 2). Even today in many places these features can still be clearly seen because there is no soil in the banks of rocks to support plant growth — for example at Fox Tor (SX636699) or at Rattlebrook (SX561848).

Streaming works are evident in nearly every Dartmoor valley. So prolific was this industry during the 16th century that in 1598 Francis Drake (then Mayor of Plymouth) petitioned The Crown to levy further dues and impose tighter restrictions on the Tinners because the amount of silt being washed off the moor into the rivers threatened to choke Plymouth Sound harbour. Plymouth was the home of the English Navy at this time, and vital for protection of the country from its traditional enemies France and Spain. However, the industry was already in decline and by the early 17th century many alluvial cassiterite deposits on Dartmoor had been worked out.

Hard-rock mining and water wheels

Consequently, the only cassiterite available in many cases was lode material, which could only be recovered through the expansion of hard-rock mining. The tin lodes had often been exposed by streaming or were located by searching for shode in the streams. The lodes could then be worked as opencast (excavated from the surface) mines, leaving long scars on the landscape known as 'beams'; (e.g. Gibby Beam and others) or 'gerts' (e.g. T Girt and others). To aid this form of exploitation the open works were often periodically flushed with water that had been collected in reservoirs, an application of the old Roman mining method termed 'hushing'. This method washed away sand and soil, exposing the lode again. In many places the remains of the extensive water collecting systems used for this process can still be seen.

Alternatively, lode back pits were sunk, a technique in which a pair of shallow shafts were sunk on the top of the lode and the lode back was then worked by a short tunnel between the shafts.

In the early 17th century two new mining technologies arrived in the UK. Black powder for blasting was first used in the south-west of England in the mines at Combe Martin *c.* 1640 and could readily be used for creating opencast trenches. Controlled blasting, on the other hand, greatly facilitated the second new technology, imported by miners from Germany. This was the digging of tunnels known as 'levels' and 'adits' for the extraction of the mineral veins deep underground by excavation of cavities known as 'stopes'.

Despite these new methods of exploitation, by the early 18th century tin mining on Dartmoor had dwindled and effectively ceased. The new technologies were limited in their application because the abundant and ever-present water — Dartmoor has more days of rain annually than anywhere else in the UK — caused persistent flooding, and only a certain amount of draining of the underground works could be accomplished by running the water off through drainage adits excavated from low down on the sides of mined valleys.

It was not long, however, until water wheels were erected at the mines. Mechanically they were used to drive the stamps and the bellows in the blowing houses where the ore was smelted, but more importantly water wheels could also drive pumps. The earliest form of 'pump' was a rag-and-chain system, where a loop of chain with rags poked through the links was run over a pulley. The chain dipped into a sump of water, soaking the rags and lifting them to the surface or to an existing drainage adit. Here they were squeezed between rollers and the water flowed away.

However, with the full onset of the industrial revolution chain water wheels could be replaced by steam engines and rag-and-chain system by suction pumps. The pinnacle of this development, when applied to south-west mining, was an engine house enclosing a beam engine. The engine house could work directly over the shaft for pumping and lifting, or could distribute power around a site through connecting 'flat' rods — so called because they were rectangular in section, *c.* ¾in (15mm) thick ´ 4in (102mm) wide and 20ft+ (6.1m+) long, and were laid on the 4in face over the rollers. Although efficient and powerful, steam engines required coal, which was expensive to import to the south-west and doubly so to carry onto the high moors. Besides, an abundant and largely free supply of water was usually not far away, so water wheels remained the principal power source for most Dartmoor mines, and by the early 19th-century tin mining on Dartmoor was again a boom industry.

A decline in mineral value coinciding with a shortage of manpower during WWI and the rising costs of ore extraction from ever deeper lodes were the final blows to the last Dartmoor mines. Some 3,500 years of tin mining effectively ended on Dartmoor in 1920 with only a few sporadic one-man ventures hanging on for a few more years.

Tin (cassiterite) mineralisation, recovery and processing

Tin formation

The main tin-bearing ore is the oxide cassiterite (SnO_2). This occurs predominantly as orange to black tetragonal prismatic crystals with an adamantine lustre and metallic glint, frequently twinned and densely packed as massive lumps, but sometimes as perfectly formed crystals termed 'tin diamonds' or elongated into fine needles. This unusual elongated form was, however, common in south-west England and was referred to as 'sparable tin' by the Devon and Cornish miners. Rarely, cassiterite occurs in a form known as 'wood tin', which, as the name suggests, has layers like a section through a tree trunk.

Ore is deposited primarily in pneumatolytic veins around hydrothermal vents or fissures and in greissen stockworks or pegmatites, both associated with granites. Quartz is the most commonly associated gangue mineral. However, cassiterite has a high density *c.* 7, is hard, Mohs 6–7 and is tough or resistant to fracture. Consequently it is sometimes found to have formed large alluvial placer deposits.

In south-west England, where it is closely associated with the granite masses, it was noticed in many mines that the richest tin mineralisation apparently occurred as a zone, like a layer in an onion, in the country rock close to the granite. From this evidence it was concluded that tin ore was deposited at a high temperature by fluids migrating away from the granite. Moving away from the granite, successive zones were rich in tin-tungsten-arsenic, then in copper, then in zinc-silver-lead, apparently deposited from migrating fluids at successively lower temperatures.

Although the actual situation is more complicated, it does serve as a general model that holds true for the Dartmoor granites, for tin is the only metalliferous mineral to occur in workable deposits, except in exceptional cases — mostly where there are north–south lead cross-courses. Such course are now known to have been deposited after the granite had solidified (for example at Wheal Betsy).

Tin mining and processing

Aside from alluvial deposits, cassiterite is recovered from mined ore by crushing it in stamps and enriching it through sedimentation over jigging tables and in buddles. The earliest and simplest type of stamps were little more than iron-shod tree trunks that worked dry ore in hollows cut into granite slabs known as mortar stones. When the ore was powdered it had to be scooped from the hollow. Later forms of stamps worked ore in a water-filled trough: as the ore was powdered it was washed onto the jigging tables. Fresh ore could be added in a continuous process.

The jigging process used to concentrate the ore was that same as that used in the streaming works. A slurry of crushed ore was run onto a gently inclined table with riffles set across the face. The cleanest tin ore, known as 'heads', settled out first and went straight to the buddles; then 'middles', which would be reprocessed; then 'tails', which went on the tips — hence 'tailings', the miners term for the piles of sand and crushed rock that account for the bulk of most mine dumps.

The art of the ore 'dresser' was to determine where best to make the cuts for heads, middles and tails. At the buddles, ore was run onto the central mound and flowed out to the edge, again giving heads, middles and tails. A central axle held a rotating arm from which hung brushes of moorland heather. These made concentric rings in the material collecting on the buddle so that rivulets of water did not form, which would obviously cut channels in the tin concentrate.

Once a reasonable thickness of 8–10in (203–254mm) of cassiterite had built up it was collected into barrels or 'kieves'. The kieves were then filled with water, which was stirred by a man with a 'vanning shovel' as the black tin was added by another man. This continued until the slurry was too thick to stir, but in the meantime the dense cassiterite would have settled out and more silt would have been run off. The kieves were then set up to be tapped gently by hammers known as 'trommels' and just as happens when wet sand on a beach is agitated, the tin packed down and the water floated out.

Tin smelting

Impure tin is initially recovered by roasting it with coke in a reverberatory furnace at >1400° C, although its ability to react with other metals can give high losses. However, tin has a melting point of just 220° C, so the impure metal is then carefully heated and 'stirred' by bubbling steam through the mix to bring a scum to the surface. The molten tin can then be poured off leaving impurities such as arsenic, lead and other impurities behind.

In the early days Dartmoor cassiterite underwent two smeltings. The first was usually done close to the mine and produced ingots of variable weight, contaminated with muck and dirt, which had been cast in moulds cut into blocks of granite. This crude metal had to be stamped by a stannary inspector within 14 days of smelting. These ingots were taken to one of the stannary towns within three months to be resmelted and cast as uniformly sized ingots of pure tin. If these steps were not achieved within these time limits, the stannary courts would pass severe punishments on anyone holding the ingots.

From *c.* 1300 'blowing houses' appeared on the moor. These were long, low buildings often with two furnances. The furnaces were little more than tall granite boxes into which cassiterite and charcoal were layered. Once lit, bellows forced a stream of air through the furnace and the molten metal ran out into mould stones. This produced 40 to 90kg ingots of high purity tin from a single smelting as there are no contaminating metal ores found in the moorland deposits.

During the tin mining revival of the late 18th century reverberatory furnaces were introduced. In these the ore and fuel were kept separate and the ore was roasted by radiant heat and combustion gasses. These furnaces were worked at a higher temperature than in blowing house furnaces and do not require forced air. However, they require coal or coke for firing, which is expensive to bring up to the moor, so few were built on the moor. More commonly, the ore was taken in raw form to Tavistock, as this was a focus for mining in the Tamar Valley.

The uses of tin

As long ago as 3500 BCE it was discovered that tin could be alloyed with other metals to make bronze (with copper) and pewter

Figure 3 Tin from the wreck of the SS Cheerful.

(with lead), giving harder and more durable materials than the individual metals on their own. Bronze remained the metal of choice for everything from weapons to farm implements for 2,000 years.

The use of tin as a rust-resistant coat for food cans began in the early 19th century, for it was a cheaper and more convenient way to preserve food than in glass jars. Until relatively recently plating accounted for much of tin application, from kitchen utensils to children's toys (now replaced by plastic), for tin adheres firmly to the iron and maintains a bright shiny finish. Tin plating continues to be its chief use today.

There are, however, more modern applications. In 1954 the UK glass company Pilkington developed the revolutionary method for flowing glass continuously onto a bath of molten tin, which gave well finished glass at low cost without the need for grinding and polishing. Even more recently, tin-silver solders are taking the place of toxic lead-based solders. Tin plating was also frequently used (Figs 3 and 4).

Ringleshuttes Mine (a.k.a. Holne Mine)

Ringleshuttes Mine shows good evidence from all three phases of tin mine development on Dartmoor.

Initially the site was worked by streaming. A long, shallow jumbled surface, lower than the surrounding moorland by as much as 3m, runs roughly north–south up the hillside with a small stream flowing within it. Unfortunately the site was partly redeveloped by later miners and the distinctive pattern of ridges and troughs cannot be seen.

Approaching up the hillside one of the first features of the later mine is a dressing floor, where coarse lumps of tin bearing rock were spalled: the practice of chipping lode stuff away from waste rock before it was crushed and the cassiterite extracted. This was connected to the mine farther up the hillside by a tramway, which is almost impossible to see on the ground but which stands out in aerial views such as those on Google Earth. Beside this tramway is a miners' track and between the two, about half way between Sandy Lane and the top end of the track, is a whim platform.

In the centre of the whim platform there would have been a heavy stone with a socket cut in the upper surface. In this sat an upright axle carrying a large, open lattice 'drum' around which a rope was wound. A donkey or horse was then hitched to a cross member from the axle, so that when it was walked in a circle in one direction the rope wound onto the drum, and in the other direction wound off, thus providing a crude winching system. This may have been for hauling on the tramway before hauling by steam engine or in the two nearby shafts was used.

The stream works continue up the hillside above the route of Sandy Lane to the point where they are cut by a shallow beam running roughly east–west. This marks the main lode; the source of the alluvial tin. However, the stream works carry on up the hill, for there is a second, smaller parallel lode farther up the slope. The beam to the east is not much developed, but to the west it soon becomes a significant excavation, dating from the second phase of the mine's development.

The beam in some places reached a depth of at least 10m, though a large quantity of waste rock from the 19th-century shaft workings was dumped into it, and forms a clearly visible surface. So it would once have been deeper at the top end than it now appears. There are also dumps of broken rock along the edges of the beam, mostly coarse white granite, but there is some cassiterite, appearing as dark orange to black crystals associated with quartz and a grey-coloured, 'peach' (soften-coloured, sometimes with a pink blush due to haematite staining) rock matrix. There is little of the black tourmaline 'schorl' often seen in other Dartmoor tin mine waste dumps.

The beam is also up to 10m wide. This does not reflect the width of the lode, which may have been only a few feet. However, the lode dipped slightly to the south, so following it down from the surface would have necessitated removing more and more overburden. Beyond a certain point the lode would have required extensive timbering and would have been hazardous.

Figure 4 A five-inch (127mm) tin-plated milk jug by Wearne & Son, Helston.

At the mouth of the beam is the site of the engine house, a relic of the third phase of development. Ringleshuttes was one of only a few mines on the moor that used a steam engine extensively, for though it had deep, rich mineral lodes there is very little water on the high ridge for water wheels. There are, however, surprisingly few records relating to the engine, whereas even at smaller mines in the lowland mining fields the installation of a steam engine was usually well documented and accompanied by a celebration when it was commissioned. For example at East Wheal Rose Mine the installation of an 80in (2m) steam engine was celebrated with a supper for the directors, seated at a table within the engine cylinder.

The chimney of the engine house at Ringleshuttes Mine was reported to still stand in *c.* 1890, but as with many of the mining artefacts on the moor the engine house and chimney were demolished by the armed forces as part of a civil defence training programme. Nevertheless, the base of the engine and the bob pit can be clearly seen sitting on a high bank beside the shaft, while the remains of the chimney are stretched out in the grass.

There are several more shafts along the course of this beam: at the top end of the lower section (from which the rock debris in the beam no doubt came) and at the entrance to the upper section, and the adit downslope of this was probably for drainage.

The westernmost end of the main beam gives the best vantage point from which to view the site and from there the extensions of the lodes over Holne Ridge, marked by another series of beams, can be seen. Holne ridge is also pocked with costean and lode back pits, numbering many hundreds, and there is a complex series of capture channels and reservoirs, which provided crucial water catchment in the summer to work the jigging tables and buddles, and for hushing.

Hooten Wheals (a.k.a. Hexworthy Mines)

It is unclear where the term ‘wheal’, meaning mine, originated. The Cornish term ‘hwel’ or’huel’, meaning hole, may be the origin, although this word may in turn be a corruption of the term ‘wheyl’, meaning a place of work. Certainly there are more wheals than mines in Cornwall, whereas the reverse is true in Devon; and as a word to mean mine the use is apparently exclusive to the south-west of England. Alternatively, the Old English term ‘hael’, meaning whole in the sense of being well, has been proposed as the origin, simply by contraction of whole to hole (in the ground) or a change in sense for ‘well’ as a hole in the ground from which to draw water.

Hooten was one of the last large working tin mines on Dartmoor (Fig. 5). It began as a tin streaming operation, with separate works along the upper course of the O brook: Dry Lake (earliest record 1240), Hooten, Hensroost and Skir Gut. The last was developed only as a stream works. Hensroost was further developed as a north–south beam with at least three shallow shafts. At this time it was amalgamated with Hooten by sharing a water system, power from the water wheels and the same ore-dressing floor. Hooten shows extensive streaming, a series of beams and several deep shafts (dating from the late 19th century when the mine was worked jointly with Ringleshuttes Mine).

Activity was cut back at the outset of WWI due to a lack of manpower, and then stopped altogether with the intention to return to full production when the war ended. The resumption of production was not a success, however. As one account recalls “the men employed were far more interested in getting to the bottom of the next bottle than ever they were of doing any mining”. Hooten ceased production in 1920 after severe flooding and although an attempt was made to reopen it in 1925 no ore was raised. The buildings remained largely intact until the mid-1930s when the stamps and New Mill building were set alight (Fig. 6, *overleaf*). Finally, during WWII the buildings were used as targets during tank training exercises.

Hooten relied exclusively on water power until its final years of operation. A small wheel and a 45ft (13.7m) diameter wheel with paddles of 5ft (1.5m) width were sited by the early dressing floors farther down the brook, to provide power to the stamps, dressing floor and tramway. When New Mill opened, power was taken from these wheels by flat rods that were laid along the line of the former tramway. There is also a wheel pit for a 30ft (9.1m) diameter wheel close to the entrance to the beam that runs down from Low’s Shaft towards the brook (Fig. 7, *page 15*). This wheel also supplied power to Hensroost by flat rods, the route of which is still clearly visible, and later also to Low’s Shaft. However, a

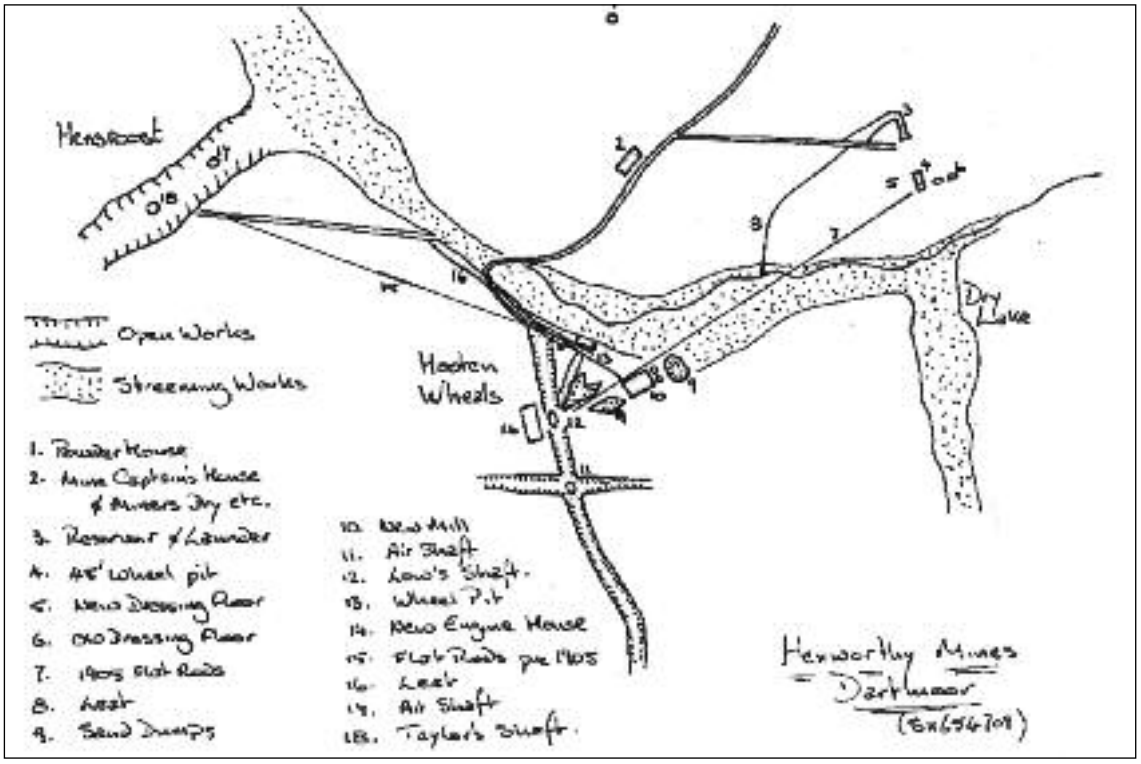

Figure 5 Plan of Hexworthy Mines.

Figure 6 The buddles and ruins of New Mill, Hooten Wheals in 2008.

steam engine was sited at Hensroost as a backup, but was never commissioned.

At the beginning of the 20th century a hydroelectric plant was built at Saddle Bridge beside the O Brook on the Hexworthy Road. Water was fed to the plant by a 16in (0.41m) iron pipe, which took water off the Wheal Emma Leat at a point on the hillside above, and electricity was supplied to the Power House beside Low's Shaft for the mine and New Mill for the stamps, jigging tables and buddles. The armature of the dynamo can still be seen in one of the buddles.

As at Ringleshuttes, the ground at is coarse granite. The cassiterite found in a lode averaging 3ft (0.9m) wide, comprised of a stockworks of thin strings in quartz. Main lode trends almost north–south and underlies *c.* 30 degrees south-west. At Hooten the granite country rock shows evidence of alteration by the hydrothermal waters close to the lode, reddening it with iron released from the weathering of biotite. At the mine itself cassiterite in lode material is now found only rarely, where it usually appears as fine orange needles, but with a little patience it can be panned from the O Brook.

Low's Shaft at the top of the slope on the line of the open works was sunk to a final depth of 50 fathoms (95m). Here ore was lifted to surface, or brought out by tram through the adit from the upper level. The ore was run down to the dressing floors at Dry Lake on a simple gravity tramway: two trucks were worked on a single set of rails connected by a cable around a drum at Low's Shaft. The full truck ran down and hauled the empty one back up, passing midway on a section of dual tracks.

Ore was spalled on the dressing floor near the big wheel. The original stamps were 'Cornish' type on the downstream side of the wheel. These were later replaced by 'California' type stamps, situated between the wheel and the end of the tramway. An axle that came directly off the hub of the wheel drove the stamps.

Stamps came in sets of four: each stamp being a long rod with a heavy shoe set upright in a framework. Each rod had a flange fitted and the axle beside it had four pins set at right angles for each set of stamps. As the axle turned, the pin engaged the flange, lifted the rod, and finally turned away to let the rod drop. The advantage of the Californian type stamp was that the rod was rifled, so that it twisted as it dropped and thus produced an additional grinding motion.

The buddles can still be seen on the flat area below the site of the Cornish stamps and for many metres in either direction up or down, the stream bank is just a continuous pile of tailings.

The well-known engineers John Taylor and Sons revived the Hooten Wheals in the 1890s and expanded the underground workings. Productivity increased, but with ore values falling to an all time low they were forced to cut back production.

In the first years of the 20th century ore values revived and Hooten came under shared ownership along with the Golden Dagger and Whiteworks mines. A new mill, of which the floors and some of the steel piers remain, was built in 1905 close to Low's Shaft. Ore was trammed into the back of the three-storey shed that covered the dressing floors. The stamps were mounted in the upper level, which was large enough for a number of sets, but only half the floor area was ever equipped. The mounting bolts in the floor still remain, as do some of the timbers that served to cut vibration and reduce noise, which must have been deafening. An alternative was applied at Hawkswood Mine on the eastern side of Bodmin Moor, where the terms of the mine lease required the stamps to be stopped when there was a service in the church half a mile away in the nearby village of North Hill.

Output at Hooten reached a high in 1908, averaging almost four tons of black tin per month at values of £85 to £95 per ton. An average of about £4,320 per year meant that in total 26 men were employed underground and 19 at surface.

Yields of black tin rarely exceeded 20lbs per ton of rock in any typical tin mine, so for every ton of concentrate something like 100 tons of rock would be brought to surface. Company prospectuses often quoted higher yields, but to do so the authors used the tin yield from a carefully selected packet, ignoring the fact that additional wall rock would have to be excavated along much of the lode to permit access. Before crushing in the stamps the ore was carefully spalled (*see above*), but even so the extensive heaps of tailings that can still be seen across the site today should come as no surprise. One estimate is *c.* 50 tons of tin concentrate from nearly 2,000 tons of crushed rock.

A leat runs all the way from Hensroost and ends in a cistern just outside the dressing floor at Hooten. A cast-iron pipe runs onto the dressing floor and some evidence suggests that there may also have been a small water wheel close by, but there is no documentation for this. Water from the pipe undoubtedly fed into the stamps, washing powdered ore into a launder and onto the Wilfley (jigging) Tables mounted on the middle level of the three-storey shed. From here another launder fed material to the buddles and then to the kieves, still within the mill building.

Photographs show that the mill building also extended quite a distance beyond the buddles, presumably covering a packing and storage area.

Beside Low's Shaft a toppled piece of wall leans over the bob pit (*see* Fig. 7). This was the end of the run of flat rods from the timber matches the distinctive shape of a timber in these photographs, indicating that this fallen timber is in fact from the top of the head frame and may have supported the winding gear.

The O Brook can be crossed on a granite clapper bridge from where a track leads to a ruined building. This was in part the mine captain's house: a two-up-two-down dwelling at the O Brook end and part dormitory for up to 12 miners. The men began their working week at 7am on Monday and finished at 2pm on Saturday. All walked to work, some as far as 11 miles across the moor from Mary Tavy (these being former miners at Wheal Friendship). Each man had to bring all his food and other supplies to last the week.

Beside the main building was a single-storey shed with a large boiler where clothes could be dried and close by were a carpenter's shop and a smithy. The steps into the carpenter's shop remain, as do the stone piers on which the floor joists once rested.

Out on the open moor behind these buildings is a circle of stones, all that remains of the mine's powder house. It had two small rooms with a dividing door. Entering the lobby, the miner would put on a pair of thick leather overshoes fixed with copper rivets before entering the powder store. The overshoes were to guard against a spark being struck from the iron hobnails in the normal boots. (One account from Vitifer Mine relates how a miner used his iron jumper bar instead of using the proper copper tool to tamp home the black powder charge into the blasting hole. A spark set off the charge and the tamper and another man were killed.

Farther down the O Brook, opposite Dry Lake, lie the remains of the older dressing floors and the pit for the big wheel. Plans show a second, smaller wheel aligned with the bank that formed the end of the tramway, but this now seems to have filled with tailings and debris from the stamps that stood between the mound and the big wheel pit. Another wheel was sited on the far side of the brook but this cannot be found.

Water was fed to the big wheel on a raised wooden launder from the launder bank, which still stands. This was in turn fed from a reservoir. During the winter there was sufficient water to run two full shifts: 7am to 2pm, then 2pm to 10pm, but during the summer the reservoir held sufficient water to run the stamps for only two hours, even though it was replenished by a leat system.

When bad weather destroyed the launder for the O Brook big wheel in 1920 the wheel stopped. In turn, flooding occurred at Low's Shaft and led to a collapse of the shaft collar and the eventual decision to abandon the mine.

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Figure 7 Remains of Low's Shaft, bob pit and dumps in 2008.

Book review

Stow, Dorrik 2010 *Vanished Ocean: How Tethys Reshaped the World*. OUP: (ISBN 978-0-19921-428-0; hardback, 300pp; £16.99 or £8.08 on Kindle

This book, aimed at the popular science market, is a 'biography' of the Tethys Ocean, from 260Ma to 5.5Ma. However, it is a great deal more than that. The author uses this subject as the thread to hold together a whole range of subjects, from elegant, clear and concise explanations of basic (and not so basic) geology to research techniques, paleogeography, paleoclimatology, marine biology, family holidays, research travels and much more.

Professor Stow is a geologist and oceanographer who specialses in deep-sea sedimentology, at present at Heriot-Watt University. He is also the author of *The Encyclopaedia of the Oceans* and of *Sedimentary Rocks in the Field: A Colour Guide* (both available from OUGS Sales).

Vanished Ocean comprises 11 chapters, each with subheadings, followed by a reading list, a glossary and a short index.

Chapter 1 sets the scene as the author embarks on his 'detective' story. However, he also explains plate tectonics, fossil dating, submarine slides and turbidity currents, biostratigraphy, magnetic field switches, the law of superposition, cyclic changes, and ice ages and radioactive dating, giving a flavour of the diversity to come.

The following nine chapters tell the chronological history of the Tethys Ocean. Each of the chapter headings is followed by a monochrome paleogeographical map of the Earth from within the period covered by that chapter. These maps also show the topography and the main ocean currents; these maps are small, however, and it can be difficult to differentiate between the tones of the grayscale used. This is a pity, as I found these maps essential in following the discussion. There are clear line drawings throughout, mainly of marine biota.

Rather controversially in chapter 7 — covering the end of the Cretaceous and the KT boundary — the author makes a most persuasive case for a slow and gradual decline in biodiversity rather than a catastrophic mass extinction. He suggests that this decline was the natural result of the huge population of marine biota present in the extensive shallow seas changing ocean chemistry and resulting in global cooling.

The final chapter gives a speculative account of future geography and climate, complete with a prospective global map 50 million years in the future.

In spite of the many digressions throughout the book to explain or illustrate points, the author somehow maintains control over the narrative, never (quite) losing the thread of his main story. If you enjoy his style of writing, this is a highly enjoyable and informative read.

— Christine Skinner, BSc (Hons) Geoscience (Open)

Book review

Clarkson, Euan and Upton, Brian 2010 *Death of an Ocean: A Geological Borders Ballad.* Edinburgh: Dunedin Academic Press (ISBN 978-1-90671-602-8; hardback, xiii + 210pp; £25)

The authors of this volume will be well known both to former students of the University of Edinburgh and to many members of the northern branches of the OUGS, having led many field trips for us over the years. Following their previous collaboration *Edinburgh Rock: The Geology of Lothian*, the authors have shifted their attention farther south, to the Scottish Borders, an area that they know extremely well, having led parties of students on excursions there for more than 40 years.

The book's title pertains to a now-vanished ocean, Iapetus, which once lay between Scotland and England in the Palaeozoic, and, with a nod to the myths and ballads of the Scottish Border region, gives a hint to the geological story to be told. Using their extensive geological knowledge and specialist skills of palaeontology (Clarkson) and igneous petrology (Upton), the authors shed light on the evidence for the existence of this ocean, its gradual closure and eventual demise at the hands of plate tectonics, and consequent mountain-building. They also deal with the aftermaths of erosion and later extension-related volcanism. A final chapter brings us quickly through the hundreds of millions of years for which there is little or evidence in this region, to the Ice Ages, which have sculpted the landscape that is seen today. The chapter titles are a good indication of what is to be found therein, some examples being 'The Southern Uplands and what they are made of', 'Small fry of the surface waters' and 'Volcanoes of the steamy wetlands'. It is also refreshing to find included a good deal of information regarding the people who have contributed to advancing our knowledge of the subject in this region through the years, such as Charles Lapworth and Gertrude Elles.

The book has been written such that it ought to be readily accessible to the layman with a passing interest in geology yet not in any way trivialised for the more advanced reader. It is well illustrated with many colour diagrams, maps and photographs. While this book in no way purports to be a field guide to the Scottish Borders, it does nevertheless identify many locations of interest and pinpoint some key exposures that the interested reader may care to visit.

A comprehensive index and a select bibliography round off the book. One small gripe I had was that often citations are given in the text and diagram captions for which no further information is given in the form of a list of full references — while of little interest to the layman, it would have been useful to have this available, even if only online. That minor niggle apart, this book can be recommended to anyone who wishes to better understand the geological evolution of the Scottish Borders.

— Stuart Swales, OUGS Branch Organiser, East Scotland Branch

Field observations in the geology and geomorphology of the Preseli hills of north Pembrokeshire

John Downes **(jd1936@btinternet.com)**

Introduction

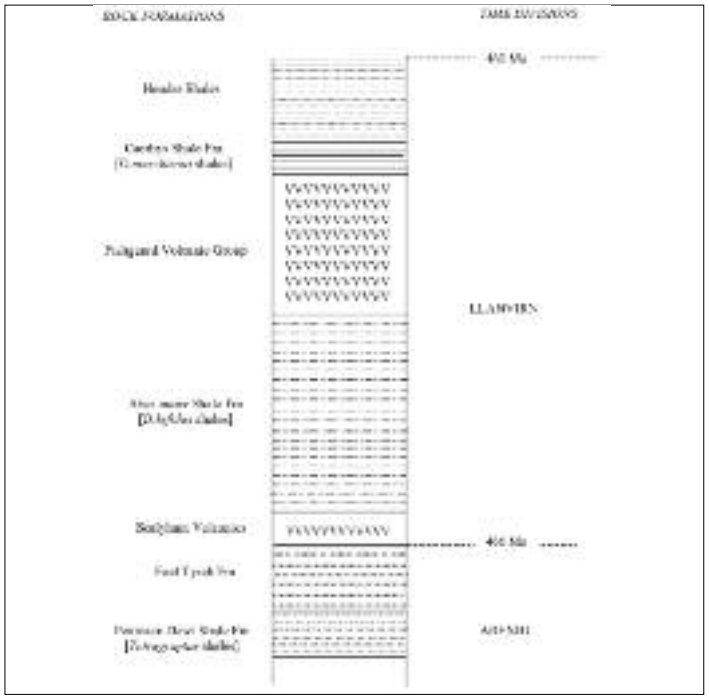
Mynydd Preseli is a range of hills in north Pembrokeshire that rise to 536m above sea level on Foel Cwmcerwyn, the highest point in the county. Preseli has long been known as the reputed source of the Stonehenge bluestones. Myths abound as to the exact way in which these stones were transported from west Wales to Wiltshire. Neolithic argonauts may have hauled the stones overland to the coast and thence voyaged on log rafts across the Bristol Channel and then overland to Salisbury Plain. Folklore even suggests that Merlin the wizard had a hand in moving the bluestones! More down-to-earth geologists tend to favour a glacial transport theory. Nevertheless the association of Preseli with Stonehenge has created a long-standing interest in these rolling magical hills with their numerous prehistoric stone circles and cromlechs.

During World War II the Preseli area was used as a training ground for the military and it would still have been MOD property today, had it not been for a successfully organised campaign by Plaid Cymru to prevent the army's continued use of the hills. Now the public has the right to walk the many paths that criss-cross the landscape and to explore the fascinating geology and archaeology.

The hills are formed of rocks of Lower Ordovician age that strike approximately ENE–WSW following the Caledonian structural trend (Fig. 1). There are several anticlines that plunge eastwards and other minor Caledonian folds affecting the strata. The area is also much disturbed by south-east-directed thrust movements, as for example on Foel Drygarn (Fig. 2), where the Fishguard Volcanic Group is thrust by at least 800m over the underlying shales, and in the neighbourhood of Rosebush, where the Sealyham Volcanics are strongly displaced by faulting. The numerous dolerite sills appear to be aligned along the strike within the mudstones and shales that dip NNW over much of the Preseli area (Fig. 3). The mudstones are often strongly cleaved, producing good quality slates that were quarried extensively in the 19th century. The rocky crags or tors that form the summit of many of the hills owe their present development largely to periglacial weathering during the late Devensian.

The following localities illustrate some of the key features of the geology of Mynydd Preseli. Obviously in order to reach the higher localities you will have to do some strenuous uphill walking.

Figure 1 Stratigraphical column for the Ordovician rocks of Mynydd Preseli.



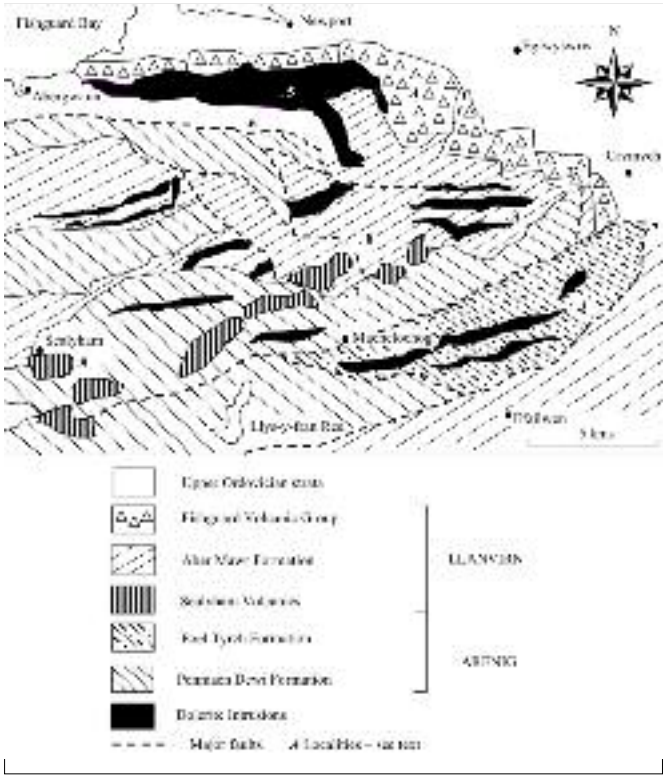
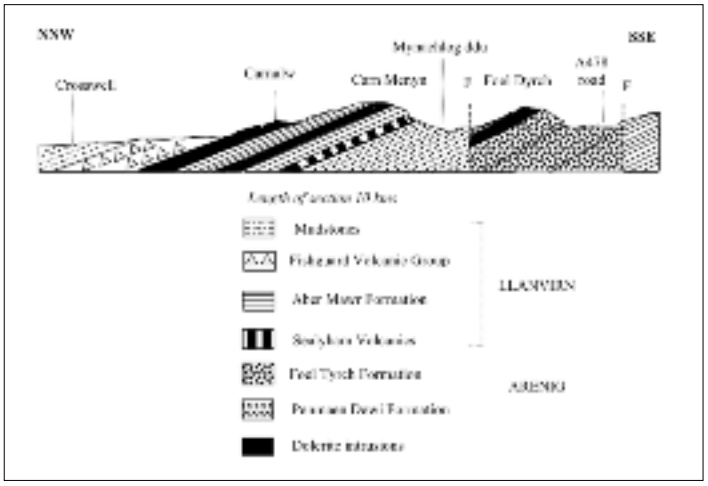


Figure 2 The geology of Mynydd Preseli.

Figure 3 Geological section across Mynydd Preseli.



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1. Tyrch Quarry [SN 157297]

This disused quarry is located on the slopes of Foel Dyrch *c.* 5km south-east of Crymych. It can be reached from the A478 Narberth to Crymych road. Parking is available alongside the entrance to Carn Wen Quarry at SN 165288. Walk down the narrow lane leading to Pentre Glas. Here the track ends and you should ask permission at the farmhouse to cross the fields to the old quarry. The rocks exposed in the quarry face and on the old spoil heaps are mostly dark coloured mudstones (Foel Tyrch Formation) of Arenig age. The dominant structural feature is a strong, closely spaced cleavage that is orientated approximately NNE–SSW. This cleavage in the mudstones was produced by intense pressure during the Acadian phase of deformation at the end of the Caledonian orogeny.

The igneous intrusions that form craggy outcrops immediately to the north-east of the quarry are formed of dolerite, a dark, medium-grained igneous rock. Unfortunately the contact between the igneous intrusion and the mudstones is not exposed in Tyrch Quarry or in the immediate surrounding area. The dolerite is probably part of the same Mid-Ordovician igneous suite that forms many of the sills that outcrop along the crest of Mynydd Preseli.

2. Foel Drygarn [SN 158336]

You can approach this locality from the southern outskirts of Crymych, where you should take the minor road signposted to Mynachlog-ddu and continue for *c.* 1.5km to a small lay-by at SN 166331. From here follow the well marked footpath north-west to the summit of Foel Drygarn, where there are three Bronze Age cairns within the Iron Age fort. The dry-stone ramparts almost completely enclose the area of the hillfort.

The igneous rocks that form craggy outcrops on the summit of Foel Drygarn are composed of interbedded rhyolite lavas and tuffs belonging to the Fishguard Volcanic Group. The tuffs represent pyroclastic deposits containing vesicles that were originally gas-filled bubbles, and also small fragments (known as lapilli) ejected from a volcano. There are examples of bedded, splintery felspathic tuffs in the crags on the south-west side of Foel Drygarn. The blue-grey rhyolite is well exposed on the eastern side of the hill where some lavas show evidence of flow banding.

3. Carn Menyn [SN 144325]

Carn Menyn is located c. 1.5km south-west of Foel Drygarn. There is a footpath connecting the two summits. However, if you wish to approach by road then there is a small parking area at Glanrhyd [SN 152318], from where a footpath leads up to Carn Menyn. This is probably the best-known rock outcrop in Preseli, as it is reputed to be the source of the Stonehenge bluestones (*see below*).

The igneous intrusions that form craggy outcrops or tors on the summit of Carn Menyn are sills of a dark, medium-grained rock. Examination of the rock shows it to be 'spotted' dolerite that is characterised by the presence of white plagioclase phenocrysts together with dark pyroxene crystals (Fig. 4). The dolerite is intruded into the cleaved mudstones of Llanvirn age. The summit outcrop is characterised by many strong vertical fractures that result from tensional stress caused by contraction when the dolerite cooled and crystallised after being intruded into the country rock. Some of these contraction joints have the appearance of columnar jointing.

Figure 4 Spotted dolerite.

The physical appearance of the tors can be described as accumulations of large irregular blocks resting on the dolerite outcrop of Carn Menyn and surrounding summits (Fig. 5, *opposite*). Large blocks litter the slopes, having been detached from the main outcrop (Fig. 6, *opposite*). Many researchers consider that the tors were produced by frost shattering under periglacial conditions during the late Devensian when the area is thought to have been just beyond the maximum ice limit. On the other hand, Linton (1955) proposed that the Preseli tors were formed by a two-stage process, involving deep tropical weathering during the Palaeogene followed by mass wasting during the Pleistocene. The 'river of stones' known as Rhestr Gerrig is a line of boulders extending southwards from Carn Menyn that provides evidence of downslope movement (solifluction) of the wet, thawed surface material above the permafrost.

Since 1921, when Herbert Thomas presented his paper to the Society of Antiquities on the source of the Stonehenge bluestones, it has been generally accepted that Mynydd Preseli was the source area of these stones. More recently in 1991, Richard Thorpe and others from the Open University matched the spotted dolerite of Carn Menyn (and several similar localities near by) to some of the 'bluestones' of Stonehenge using petrographic and geochemical analysis.

What has long been contested is how the stones actually reached Stonehenge from south-west Wales. It has been proposed by archaeologists that these bluestones were transported by Neolithic people across Pembrokeshire to Milford Haven and thence by raft across the Bristol Channel, and finally overland to Salisbury Plain. By contrast, most geologists have long been of the opinion that the stones were carried as erratics by the earliest advance of the Irish Sea ice that crossed the Preseli and extended eastwards up the Bristol Channel towards Salisbury Plain. Thus, a source of bluestones was more locally available to the builders of Stonehenge.

4. Pentre Ifan [SN 098368]

This is probably the most famous Neolithic cromlech in Pembrokeshire (Fig. 7, *opposite*). It can be approached by signposted minor roads either from the A487 near Nevern or from the B4329 at Brynberian. The structure dates from *c.* 3500 BC and the existing stones formed the portal to the main communal burial mound, which was *c.* 36m long. The massive upright pillars

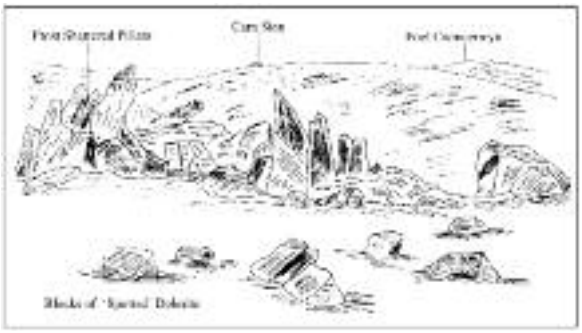


Figure 5 Carn Menryn — sketch of features.

Figure 6 Carn Menryn.

and the capstone are composed of agglomeratic tuff (volcanic ash) from the Fishguard Volcanic Group that outcrops in several localities in the surrounding area.

5. Carn Ingli [SN 063373]

Carn Ingli rises to 347m above sea level and is the highest point in the western part of Mynydd Preseli. The summit is formed of rocky crags that dominate the skyline to the south of Newport. You can approach the locality along the narrow lane leading from Newport to Cilgwyn. After *c.* 2km branch off to the right and continue for *c.* 500m to a small lay-by at SN 070374. From here a footpath leads directly to the top of Carn Ingli. About half way up the hill you will see two stone-built pillars standing on a flat grassy area. These pillars supported a cable drum that controlled the descent of rail wagons carrying stone down the incline to a crushing plant on the Cilgwyn road. The quarry closed in the 1930s and is now much overgrown.

Geologically, Carn Ingli is composed of a massive sill-like intrusion that strikes ENE–WSW and dips towards the north-west. Strongly jointed dolerite is exposed on the eastern side of Carn Ingli and in places there is evidence of columnar jointing, the result of magma contraction during cooling. However, according to the British Geological Survey (Sheet 210, Fishguard) the western crags are composed of microtonalite. This is a felsic igneous rock of medium-grain size and rich in silica and plagioclase feldspar. All the rocks are deeply fissured and the joints have been widened by freeze-thaw action, particularly under periglacial conditions at the end of Devensian times. The upper eastern slopes of Carn Ingli are covered with large frost-shattered boulders, which form a blockfield. The intrusion is underlain by shales (Aber Mawr Formation) of Llanvirn age that form much of the lower ground bordering the Cilgwyn road.

Carn Ingli is also an important archaeological site. The Iron Age fort has well preserved stone ramparts on the north side and hut circles can be distinguished within the site. In recent years Carn Ingli has become a place of pilgrimage for readers of the *Angel Mountain* saga by local author Brian John. The mountain plays a central part in the story of Martha Morgan, the early 19th-century matriarch of Plas Ingli.

Figure 7 Pentre Ifan.

6. Cwm Gwaun [SN962373-SN057355]

The Afon Gwaun drains the north-west slopes of Mynydd Preseli and its attractive wooded valley is known as Cwm Gwaun. The easiest approach to Cwm Gwaun is along the B4313 from Fishguard, through Llanychaer, then descending the narrow lane to Cilrhedyn Bridge and following the valley upstream to Pontfaen. Continue along the valley until you reach Llanerch [SN057355], where there is a conspicuous right-angle bend in the road and a small lay-by suitable for a few cars. In this locality the valley is several hundred metres wide but there is little evidence of surface drainage. Here we are standing on the watershed between the Gwaun, which flows westwards to Fishguard Bay and the Clydach stream, which flows northwards to join the Afon Nyfer at Newport.

The spectacular Gwaun-Jordanston meltwater channel system in the Fishguard area (Fig. 8, *overleaf*) was formerly thought to have been cut during the Late Devensian by water overflowing from proglacial lakes trapped between the Irish Sea ice sheet to the north-west and Mynydd Preseli to the south-east (Charlesworth 1929). However, it is now considered more likely that subglacial meltwater flowing beneath and marginal to the ice sheet eroded the channel system. The waters escaped south-westwards along the Gwaun Valley and southwards through the Scleddau overflow channel.

Bowen and Gregory (1965) point out that the long profile of several of the valleys within the drainage system contain humps. These topographic obstacles would be overridden when meltwater was flushed along the channels as hydrostatic pressure built up. Later, as the ice front retreated, meltwater escaped northwards and westwards directly into Cardigan Bay and the Gwaun

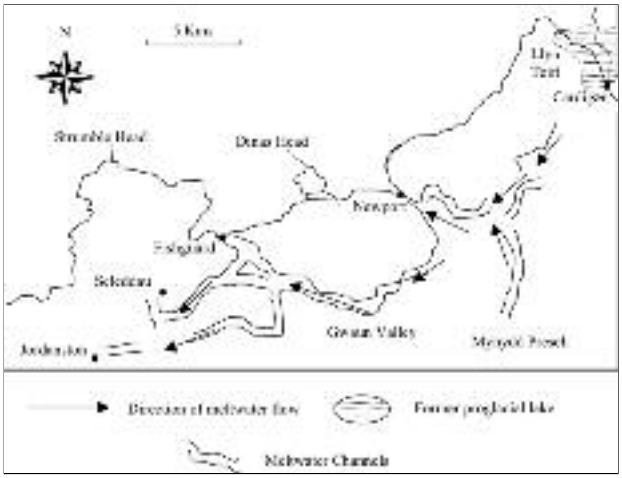


Figure 8 The Gwaun-Jordanston meltwater channel system.

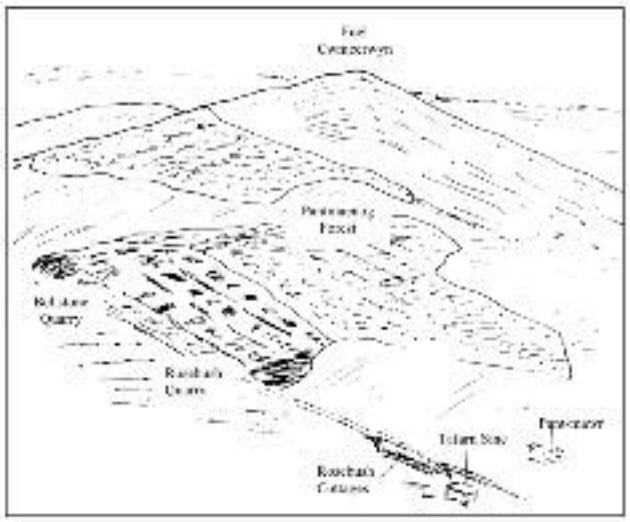
channel was abandoned. Today this relict subglacial humped section at Llanerch represents a modern drainage divide and the steep-sided Gwaun trough remains a testament to the former power of subglacial meltwater under hydrostatic pressure. Several minor subglacial tributary channels such as Cwm Mawr [SN044352] can also be recognised along the upper reaches of the Gwaun Valley.

7. Bellstone and Rosebush slate quarries [SN 078300]

The B4329 Haverfordwest to Cardigan road is the best scenic route across Mynydd Preseli. At New Inn crossroads [SN 061301] take the B4313 signposted to Maenclochog, after 1.5km turn left into Rosebush village and park near Y Tafarn Sinc. This pub, with its distinctive corrugated iron roof, was formerly called the Preseli Hotel. It was built in 1876 when the Maenclochog railway was opened to provide a link between the quarries and Clunderwen on the main line. The street of terraced cottages in the village provided accommodation for the quarrymen.

The slate quarries were excavated on the western flanks of Foel Cwmcerwyn immediately north of Rosebush (Fig. 9). They are easily accessible along the track leading past the cottages. The first quarry to be opened was Bellstone, in 1825, the most northerly of the workings. A deep pit drained by an adit was used to extract some of the best slates. Bellstone closed in 1891. Rosebush Quarry opened in 1842 and expanded rapidly after the opening of the railway from Clunderwen (which was later extended from Rosebush to Fishguard). The slate produced at Rosebush was of high quality and was used for roofing the Houses of Parliament. Today the only quarry buildings to have survived are the ruins of the locomotive shed and part of the dressing shed adjacent to the trackway. Parts of the old quarries workings are now flooded (Fig. 10).

The rocks at Rosebush (belonging to the Aber Mawr Formation) were deposited as turbidites from debris-laden submarine currents that flowed down the shelf slope into the southern part of the Welsh Basin during late Arenig times. Numerous volcanic centres existed at this time and volcanic ash was laid down and interbedded with mud and sand in the surrounding seas. These sediments were later subjected to intense pressure during the Caledonian orogeny and now exhibit strong cleavage, which strikes NNE–SSW and dips steeply to the west. You will find it easier to examine the clean surfaces of slate on the spoil heaps. On some surfaces you should be able to identify bands of light-coloured fine sandstone, dark grey mudstone and lighter



Figur 9 Foel Cwmcerwyn and Rosebush quarries.

grey siltstone in a fining upwards sequence (Fig. 11, *opposite*). The mudstone layers are generally much thicker (100–500mm) than the others and produce the best slates because of their homogeneity. The layers represent the original bedding planes and these are roughly at right angles to the cleavage planes along which the slates split.

8. Foel Cwmcerwyn [SN 095312]

The easiest way to reach Foel Cwmcerwyn is to park at Bwlchgwynt [SN 075322] on the B4329, then follow the footpath east towards Bwlch Pennant at the junction with the track from Rosebush Quarries. Continue along the boundary of the Forestry Commission land (Pantmaenog Forest) then turn south on the path leading up to the summit of Foel Cwmcerwyn. Alternatively, you can park in Rosebush village and take the track through Pant-mawr farm, famous for its cheese making. This route to the summit follows the eastern boundary of Pantmaenog Forest and provides good views of the crags of Carn Afr formed of a faulted slice of trachyte lava belonging to the Sealyham Volcanic Series.

On a clear day there are some excellent views from the summit of Foel Cwmcerwyn across Mynydd Preseli and the surrounding area. You should be able to identify the rocky tors of Carn Sian, Carn Menyn and Foel Drygarn orientated roughly ENE. The TV

Figure 10 Rosebush Quarry.

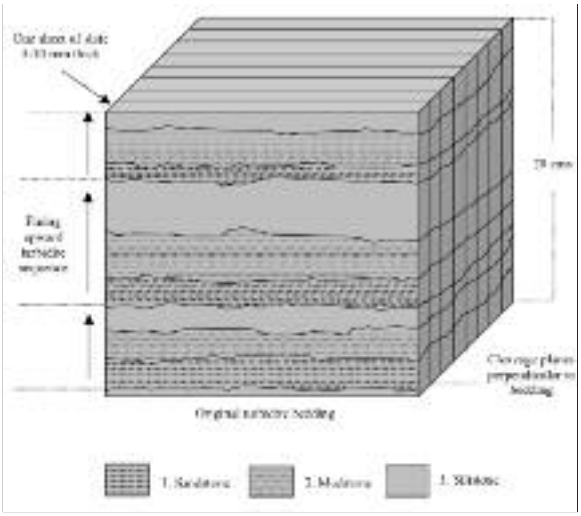


Figure 11 Bedding and cleavage in a block of slate.

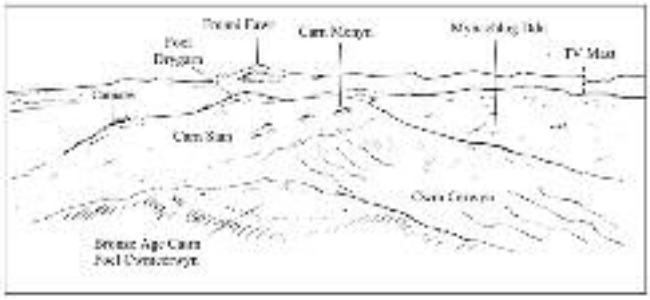


Figure 12 View eastwards from Foel Cwmcerwyn.

mast at SN 172306 provides a useful location marker (Fig. 12). The view to the north-west shows Carn Ingli and Afon Nyfer estuary at Newport. About 200m east of the triangulation pillar is Cwm Cerwyn, where the headwaters of the Eastern Cleddau rise. There is an overgrown disused slate quarry in the headwall of the cwm, where strongly-cleaved mudstones of Llanvirn age are exposed. On the south-east side of the quarry, near the original entrance, there is a wedge of the Sealyham Volcanics composed of vesicular rhyolites and splintery tuffs that are faulted against the shales. A more accessible outcrop of the Sealyham volcanics occurs at Garn Turne Rocks, 2km south-east of Sealyham (*see below*).

9. Garn Turne Rocks [SM 979272]

This craggy outcrop of Lower Ordovician volcanic rocks is located *c.* 3km north-east of Maiden Castle. Drive northwards along the A40 through Wolf's Castle; turn right on to the narrow lane leading to Sealyham, then turn right again, cross the bridge over Afon Anghol, pass St Dogwells Farm and Garn Turne Rocks occupy a slight rise *c.* 1km ESE of the farm. The rocks are not easily seen from the road due to the high hedges, and you need to look carefully for the narrow overgrown entrance with a metal gate that stands alongside a small lay-by. There is no sign to mark the entrance despite the fact that it is a recognised archaeological site and contains the remains of a Neolithic chambered tomb.

Cross the field to the rocky tors that outcrop beyond the standing stones. This is an important geological locality, as it provides one of the few accessible exposures of the Sealyham Volcanics. The outcrop consists of a much-weathered and fragmented rhyolitic rock. The fragments are mostly < 100mm across, although there are a few larger-sized clasts. This rock can be described as an agglomerate containing fragments of lava that were blasted from a volcano in early Ordovician times. Pyroclastic material including volcanic ash, pumice and vesicular lava can be identified in the outcrop.

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Maps

British Geological Survey 1:50,000 Sheet 210 Fishguard
Ordnance Survey 1:50,000 Sheet 145 Cardigan & Mynydd Preseli
Outdoor Leisure Map 1:25,000 Sheet 35 North Pembrokeshire

Author

John Downes is the author of *Folds, Faults and Fossils: Exploring Geology in Pembrokeshire* (2011; published by Llygad Gwalch in Pwllheli).

Book review

Goodenough, Kathryn M. and Krabbendam, Marten (eds) 2011 *A Geological Excursion Guide to the North-West Highlands of Scotland*. Edinburgh Geological Society in association with NMS Enterprises (ISBN 978-1-90526-753-8; 222pp; laminated card cover, £15.99)

This is one of the best Field Guides I have used. The editors are senior members of the British Geological Survey who have specialised in the north-west Scottish Highlands, and the *Guide* incorporates recent research into the area. Their hands-on experience and scholarship shows.

The *Guide* focuses on the bedrock geology of the North-West Highlands Geopark and is written for those with some knowledge of geology. It starts with 27 pages setting the context for a series of 'Excursions', describing the geological framework of the North-West Highlands, the structural units (with stratigraphic logs, cross section and diagrams) and the igneous rocks of the area.

The heart of the *Guide* is 15 detailed descriptions of excursions in areas between Ullapool in the south and Durness and Eriboll on the north coast (there is a map showing where they are), each of which will take about a day. Many classic localities of the Moine Thrust and its foreland are included, there are soft rocks as well as hard rocks together with popular geo-visitor spots such as the Glencoul Thrust, the much photographed trace fossils of the Pipe Rocks, Knockan Crag, Smoo Cave, and the Peach and Horne Monument at Inchnadamph. Each excursion comprises visits to three to 18 coastal and inland Localities and is introduced by a description of the purpose of the excursion, the aspects of geology to be covered, and the OS and BGS maps covering the area. There is then a succinct description of the terrain and an estimate of the time required. Pay good heed to both, as you will often need your hiking boots and a few of the excursions are quite challenging; and the time can vary depending on physical ability and your personal inclination to study locations in greater or less depth. I am not as fit as I was and generally needed a bit more time than indicated. There is also helpful advice on access, including what to do at places where there are constraints on the number or size of vehicles.

The introduction to each Excursion is followed by a geological map showing the Localities to be visited and detailed access / parking instructions. Grid references (usually 8 figures — I found them accurate) are given for each Locality so that navigation should be no problem and you can use your GPS to walk right up to the exposure. There is a good commentary and in depth discussion of the up-to-date interpretation of structural relationships, sedimentology and metamorphic history and of the mineralization of the Locality and where appropriate the history of its geological investigation. There's plenty material here for first year students and for experienced graduates and if you're in a group the latter can usefully help the former. Colour photos and diagrams supplement the text.

After the excursions there are a further 11 individual roadside stops, which do not fit easily elsewhere. I recommend that you do them as and when you can. There is an extensive list of references and some recommendations for further reading about the general geology of the area and the history of research, together with a note of books providing up-to-date detailed reviews of the current state of scientific knowledge about the geology of Scotland.

If you are interested in geology and plan to visit the North-West Highlands Geopark you should certainly buy this *Guide*. There is enough material in it for at least two or three visits to the area. If you were not planning a trip to north-west Scottland, then you should reconsider — both the geology and the scenery of this remote and sparsely populated area is magnificent and, as the *Guide* makes clear, its geology is important to our understanding of the science.

OUGS members can purchase this *Guide* (and other Edinburgh Geological Society publications) at EGS Members prices by quoting their OUGS membership number:

- see http://www.edinburghgeolsoc.org/p_sales.html)
- contact jackson.geol@btinternet.com

— Bob Morley CA, BSc Hons (Open)

OUGSME field trip to the Bavarian-Bohemian Geopark, October 2010

Elisabeth d'Eyrames[1], David Kopsch[2], Eileen Lawley[3], Neil Lawley[3], Michael Molloy[4] and Fred Owen[5]

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Introduction

Michael Molloy

The Bavarian-Bohemian Geopark covers four rural districts in north-east Bavaria and two in Bohemia. It arguably encompasses the richest and most varied selection of sites of geological interest in central Europe. During the Variscan orogeny, a number of micro-continents or terranes, which were parts of the Armorican Assemblage, were swept up in the collision between Laurusssia and Gondwana, to form Pangea, between the Late Devonian and mid-Carboniferous. Three of these units form the basement rocks of the Geopark. They are: the Saxothuringian Zone, the Moldanubian Zone and the Bohemian Massif.

The Saxothuringian Zone consists of a high-grade gneissic core and lower-grade Palaeozoic sediments, with extensive granite intrusions. The Moldanubian Zone represents the internal zone of the orogen, and comprises high-grade metamorphic rocks and abundant Late Devonian to Late Carboniferous granites and migmatites. Farther south, this unit forms basement inliers or windows within the Alpine nappes. Historically, owing to the similarity in their constituent rocks, the Bohemian Massif and the Moldanubian Zone were considered to be one unit. More recently, however, palaeomagnetic measuremments have determined that the Bohemian Massif has rotated some 140° anti-clockwise relative to the Moldanubian Zone, strongly indicating that it was a separate terrane.

The northern boundary of the Bohemian Massif is formed by the Eger or Ohře Rift Valley, which is approximately 300km long and 50km wide. The rift system is part of the European Cenozoic Rift System, together with the Rhine and Auvergne Grabens. The Eger Rift evolved at the Upper Cretaceous/Tertiary boundary and reactivated the Variscan Saxothuringian/Moldanubian suture zone. The main rifting phase took place between 42Ma and 49Ma ago, with the graben formation and intraplate alkaline volcanism. The rifting process is still active, and results in CO_2 emission at the surface in north-west Bohemia. It is the source of the mofettes fields and of the continued uplift in some southern parts of the rift, accompanied by earthquake swarms.

Day 1 (25 October 2010): KTB, Franconian Lineament and Parkstein

Eileen Lawley (text) and Neil Lawley (photos)

We drove *c.* 200km north of Munich, through fields where hops and maize had grown, to the site of the German Continental Deep Drilling Program (KTB) near Windischeschenbach. We were welcomed by the head of the KTB Geocentre, Dr Frank Holzförster, who was to be the guide for our visit of the facilities. The project was initiated in the 1980s with the intention of studying continental crust and hoping to reach the Moho , where the brittle continental crust becomes ductile. The site for drilling was chosen because it is a suture zone formed during the Variscan orogeny *c.* 380–320Ma when the Rheic Sea between Gondwana and Laurussia closed to form the supercontinent of Pangaea. Previous geological mapping had indicated that there were four nappes in a vertical section (Fig. 1).

Figure 1 The KTB Drilling Tower.

During 1987–9 a pilot hole was drilled to 4000m, and 97% of the core was recovered for investigation. The thermal gradient was found to be 20°C^{-km} so it was hoped that a depth of 11km to the underlying basalt layer — deduced from magnetic, seismic and gravity measurements — could be attained before the instrumentation became too hot to use. Drilling of the main borehole 200m to the east of the pilot hole began in 1990, but the thermal gradient at that spot was found to be 30°C^{-km}. By 1994, after reaching 9,101m, the temperature found to be 280°C and the pressure 3.8 kbar, so the drilling had to be stopped, because at these temperatures and pressures the electronic instruments are unreliable. The brittle-ductile zone had been reached at a lesser depth than expected because of the higher thermal gradient.

We looked at the site exhibition, inspecting the diamond drilling bits and samples of core retrieved and learned that the borehole was *c.* 300mm wide with a 120mm drill pipe (Fig. 2). For most of us the concept of 'mud' was fascinating. Having heard about this term in connection with recent attempts to stop the flow of oil from the Deepwater Horizon rig, most of us thought that the 'mud' used was a mixture of rock and water recovered from the borehole. In fact it seems to be a miraculous substance consisting of water and hectorite, which is solid when stationary but becomes a viscous liquid when shaken or stirred. This mixture is pumped downwards through the borehole and is used to power the motor driving the drill bit. It is also used to lubricate and cool the drill bit, and returns to the surface in the space between the walls of the borehole and the drill pipe or string, carrying waste away as small fragments of rock.

Figure 2 Drill bits and a section of the drill core.

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As only *c.* 600m of core were recovered from the main borehole, these fragments provide valuable information about the rocks encountered.

We climbed some 18m of the 85m high drilling rig to watch a film about the changing of the drill bit. Here we also saw the platform and machinery where this operation took place. At the deepest depths 237 drill pipe segments, each 39m long, had to be brought to the surface, disconnected and moved to a temporary storage area on the platform using an automated pipe-handling system called an 'iron rough neck'. After the bit had been changed the whole operation had to take place in reverse in order for drilling to start again.

Next we moved to another exhibit to examine some of the drill pipes used and the 'business end' of the drill, which extended for several metres. We studied the sensors used to detect deviations from the vertical and redirect the drill, as well as the instruments integrated into the end section.

The drilling process and instruments developed have greatly improved knowledge about deep borehole drilling and were further developed for use in the drilling industry. Continuing research takes place using magnetic, thermal and other geophysical and chemical measurements taken in the borehole and comparing these with surface measurements.

After thanking Dr Frank Holzförster for his excellent tour we met up with Dr Andreas Peterek of Bayreuth University and the Geopark Bayern-Böhmen, who was to be our guide for the rest of our geological explorations. First we took a short ride to the top of the Franconian Lineament to view the line of the fault zone from a scarp *c.* 200–300m high. This zone trends NW–SE for *c.* 300km and is *c.* 20km wide, and forms the western edge of the Bohemian Massif. This line was to play a prominent role in our other explorations of this area.

Mesozoic sediments lie on the western side of the Lineament, which shows subsidence, indicating tension. Crystalline metamorphic rocks of the Bohemian Massif that formed during the Variscan orogeny lie to the east under compression from the Alpine orogeny. Measurements from the KTB, which lies a short distance to the east of the fault, have provided further confirmation of this compression and its rock composition.

We next made a short trip to Parkstein, a volcanic cone formed from a basaltic intrusion, lying a little to the west of the Franconian Lineament (Fig. 3). The basalt intruded under water and the phreamagmatic reactions caused explosive combinations of magma and country rock to form a breccia containing large boulders up to 0.4–0.5m in diameter. The columnar structure formed is unusual: the columns are rather narrow (only up to 200mm in diameter), and as the columns form perpendicular to the cooling surface we were able to follow the curve of this surface to visualise a crater 150–200m wide. We learned that this basalt intruded under a lake or maar 20Ma ago, and that 200–300m of sediment has since eroded away, thus exposing the columns and breccias that we see today. We were also able to enter some tunnels — dug into the breccia for storage — to see other large boulders of country rock (Fig. 4).

Figure 3 Basalt columns at Parkstein.

Figure 4 The Parkstein breccia/ basalt contact.

This ended our first day in the Geopark Bayern-Böhmen and we arrived at our first overnight stop in Neuhaus.

Day 2 (26 October 2010): Moldanubian and Saxothuringian Tectonic Units

Elisabeth d'Eyrames (text) and Neil Lawley (photos)

Dr Peterek was also our guide on Day 2, along with Dr Johann Rohrmüller of the Bayerisches Landesamt für Umwelt, Geological Survey Bayern (Fig. 5).

Figure 5 Dr Andreas Peterek (left) and Dr Johann Rohrmüller (right).

The tour took us north, to see the tectonometamorphic units of the North Bavarian basement (Moldanubian Unit, Saxothuringian Unit, Münchberg Nappe Complex), including the late Variscan granites. We followed approximately the line of the Franconian Lineament, which we had seen and discussed with Dr Peterek on our way to Parkstein on Day 1.

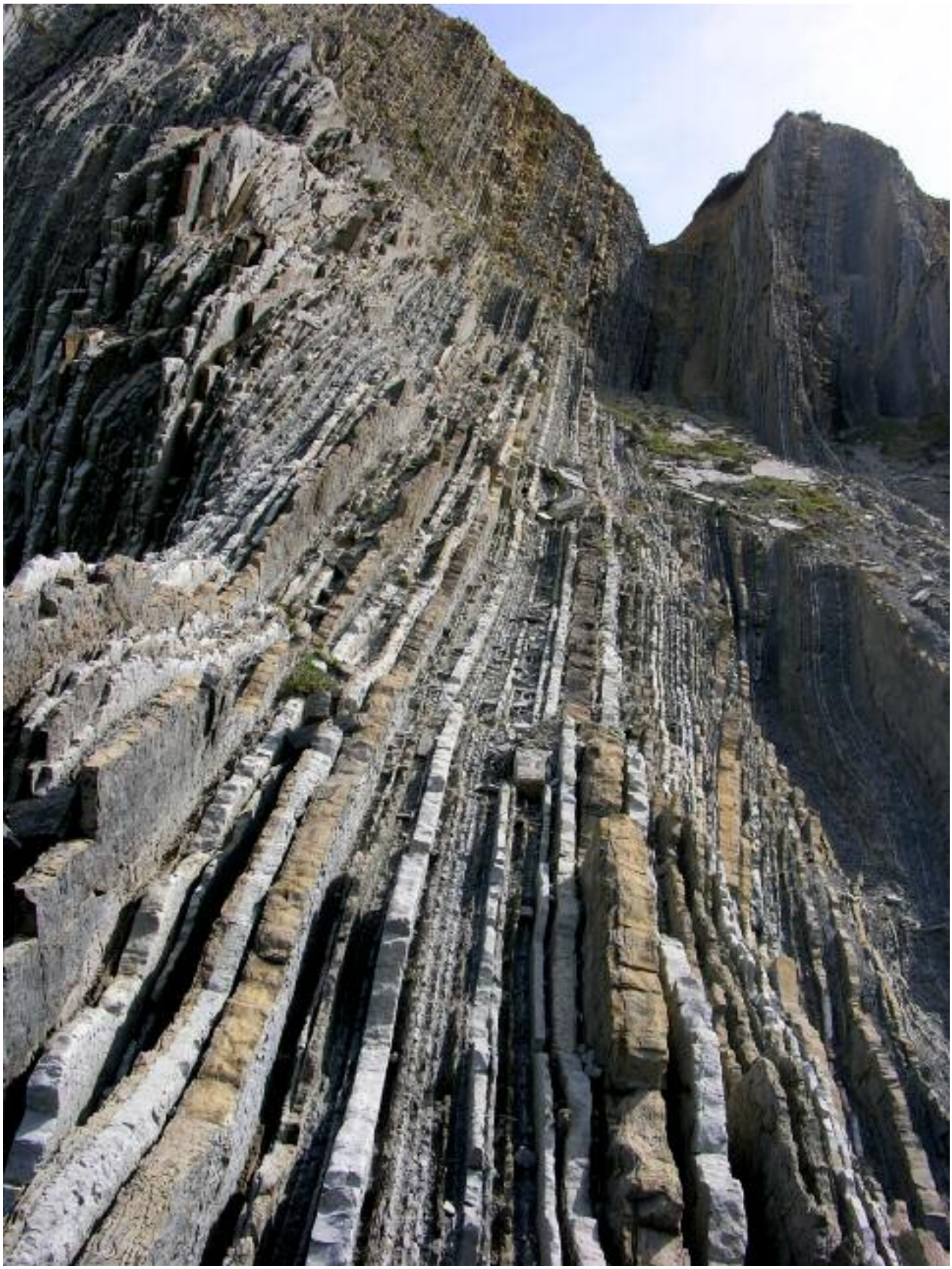
Our first stop was in the Oberbaumühle Quarry, operated by the Basalt-Actien-Gesellschaft, where we were greeted by two of the company's geo-engineers. The quarry produces aggregates from amphibolite, hornblend-gneiss and para-gneiss, which form the lower Paleozoic basement rocks of the Erbenorf-Vohenstauss Zone (ZEV). The rocks have been brecciated by the intrusion of the nearby Upper Carboniferous Leuchenberger granites, during the Variscan orogeny, some 310Ma ago. Some veins of granitic

Moyra Eldridge Photographic Competition 2011 Winners

Winner for Geological Landscape category: Jenny Forrest (Walton Hall Branch)

Blue Lias Cliffs at Dunraven Bay

This photograph is taken from the viewpoint at Dunraven Bay on the south coast of Glamorgan. Looking towards the south-east from the viewpoint, the Blue Lias cliffs extend from Dunraven Bay to Nash Point in the far distance. The contact between the two units of the Porthkerry member of the Blue Lias is clearly seen. The grey coloured lower Unit A has equal proportions of mudstones and limestones; the buff coloured upper Unit B has more limestones than mudstones. The low tide has exposed the wave-cut platform and the cliff top is the 60m Pliocene platform.



Winner for Geological Feature category: Tyrone Lynch (Mainland Europe Branch)

'The Flysch', Zumaya 1 (Zumaya Section, Itzurun Beach (Playa de San Telmo), Zumaia (Zumaya), Guipuzkoa, Basque Country, Spain (42˚18.00'N/2˚15.30'W).

These are nearly vertical, alternating Eocene limestone, marl and sandy turbidite beds. The beds are between 20mm and 200mm thick.

Winner for Industrial Geology category: Eileen Lawley (Mainland Europe Branch)

Rio Tinto Zinc, Andalusia, Spain

This picture shows an open-cast mine near Minas de Rio Tinto Museum, Nerva in south-west Spain. There are many mineral deposits, mainly sulphides, which have been mined since Roman times in this area, known as the Iberian Pyritic Belt. The 'belt' was formed as a result of the tectonic collisions that formed the Betic Belt. The mine employed up to 12,000 people, some of the British engineers living in an English town built especially for them in Huelva, and called Bellavista. We took the picture while visiting Seville in our boat, as we are retired and spend our time permanently on holiday doing this sort of thing.

Winner for AGM Delegates' Popular Vote category: Chris Popham (South West Branch)

'Copper Blue Water'

A ladder descends into the copper blue water of a flooded 'winze', a short access way between levels in a mine (as distinct from a 'shaft', which would typically reach the surface.)

This mine in the Tavy Valley was in the heart of the 1800s copper-producing belt, but as with many Devon mines, when the demand for copper fell it became uneconomical to continue working the deeper levels and the mine closed in the 1880s. Again, like many mines in this area, it re-opened in the early 1900s until c. 1920 as an arsenic producer; above ground this phase of working has left many relics, including two Brunton calciners and the remains of a large pelton wheel — a type of water driven turbine.

Geologically, the productive parts of the mine worked multiple east–west striking lodes with very steep (almost vertical) dip angles in the killas country rock (heat-baked sandy mudstones). In places the levels are driven short distances, apparently along ore stringers into the granite, but the lack of development work and stopeing on these adits suggests that there was no mineralisation in the granite, as was typically the case in these copper mines.

This photo was only possible with the co-operation of the other members of our group, who kept well clear, as the slightest disturbance of the water flowing into this winze quickly carries in extremely fine silt, which reflects the light from the flash and gives a complete 'white out'. To get the photo I had wrapped a slave flash gun in a clear plastic bag so that my friend Tom was able to hold it with the head of the flash just dipped under the surface of the water. Consequently, when the remote flash was triggered the light was directed down into the water rather than reflecting off the surface. In the meantime the flash on the camera was obscured so that just sufficient light was available to light the walls of the passage and trigger the remote but again without giving a direct line of sight to the surface of the water, which would have produced a reflection. The surface of the water can be seen in the bottom right of the photo where there are a few small ripples, and in the top left where the water surface makes a line along the wall.

I was able to get this and another photo taking turns with Tom ,who also got two photos before the water began to fill with silt and the opportunity was lost until another day.

Figure 6 Oberbaumühle Quarry, veins of 'Flaser' in the amphibolite rocks.

intrusions could be seen in quarry rock face; metamorphism took place in the Devonian 380Ma ago (Fig. 6).

The source rock for the amphibolites is lower Paleozoic (700–500Ma) basalt and volcanic tuffs. Although there is a banded structure, mainly due to the tuff deposits, it is not a gneiss, as the source rock is not a plutonic one. The banded structure is called 'flaser': the white-coloured bands are plagioclase-rich and the dark-coloured bands amphibole-rich. Typically, the amphibole here is hornblende, but green patches of chlorite and epidote are also visible, brought about by low-temperature mineralisation, where the amphibole is in near contact with the granites.

Our second stop was at the Marienstollen quarry *c.* 1km north of the town of Erbendorf. Erbendorf has a history of 1,000 years of silver and lead mining in veins cutting through Permo-Carboniferous sedimentary rocks. Up to 1920 coal was also mined in the Permo-Carboniferous Rotliegendes area. The quarry is part of the northern end of the Erbendorf –Vohenstrauss nappe complex, where the amphibolite and para-gneisses constitute the nappe (Fig. 7).

Figure 7 Ultramafic rocks in the Marienstollen Quarry.

The Marienstollen is an old talc quarry. The talc runs in veins through ultramafic serpentinite rocks. We were at an outcrop of the remains of an ophiolite, which had been stranded during the Devonian Variscan orogeny some 395Ma ago, following the closure of the Saxothuringian Ocean. The olivine and pyroxene contained in the original peridotite ultrabasic rocks have been changed into serpentine by interaction with water at low temperatures. Two phases of metamorphism can be detected: the first is regional; and this was overprinted by a later, second phase of contact metamorphism.

The seam of ultra mafic rocks shown in Figure 8 forms the boundary between the Moldanubian tectonic unit to the south and the Saxothuringian unit to the north.

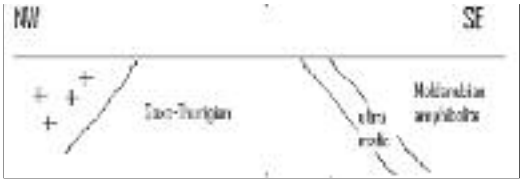


Figure 8 The Saxo-Thuringian/Moldanubian Suture.

Clearly, however, two outcrops cannot be respresentative of a whole tectonic unit. Those we saw in the Oberbaumühle and Marienstollen quarries are both characteristic of the high-grade metamorphic rocks associated with the Moldanubian zone. As we moved onto the Saxothuringian zone, we would expect to find lower-grade Lower Palaeozoic sediments, and this is exactly what we did find.

Our third stop was at a sedimentary outcrop of grey-green coloured quarzitic schist, known as the Phycoden Group, exposed in a road cutting in Kranichstein. The deposits contain trace fossils of fucoiden algen beds. For those you who have been in north-west Scotland, you might remember the Cambrian fucoid beds next to Loch Assynt. The sediments display a metamorphic overpint with small-scale tectonic structures, rather than genuine metamorphism, in particular a foliation pattern of small isoclinal folds, called transposed foliation (Fig. 9). Figure 10 shows the sequence that leads to this type of foliation.

Figure 9 (above) Transposed foliation.
Figure 10 (right) The sequence of transpositional foliation.

This low metamorphic unit was folded during the Variscan orogeny, over different folding episodes. It was buried by faulting along the Franconian Lineament and later exhumed by Permo-Carboniferous and Upper Cretaceous uplift. This is not an exposure to be admired from 5m distance, for it is decidedly filigree, with the structures more measurable in millimetres (Fig. 11).

Figure 11 Transposed foliation at Krannichstein.

We continued the trip into the Fichtel Mountains, where we stopped at the community centre in Bischofsgrün to eat our packed lunches. Bischofsgrün is situated in the south-west corner of the Bavarian part of the Fichtel Mountains, overlooking the two highest elevations: the Schneeberg at 1,051m and the Oxenkopf at 1,024m. The Fichtel Mountains comprise *c.* 40% granites — which form the topographic highs — surrounded by metamorphic basement rocks consisting of schists and marble. The Upper Carboniferous granites intruded the metamorphic units over a period of 30Ma to 40Ma, some 325–290Ma ago.

Our next stop was at a granite quarry north of Schurbach. The Koesseine granite found here has been quarried for more than 100 years, for its particular blue-grey colour. It is a porphyritic granite with xenoliths of country rocks, and also contains cordierite minerals (Fig. 12).

Figure 12 Koesseine granite from Schurbach.

In 1998 there was a new investigation about the age and shape of the granite intrusions. It appears that the older intrusion is a batholite 1–2km thick, which shows magma differentiation as it spreads out. The younger intrusion has a different root zone and is up to 8km thick. The discussion about its shape suggests either different roots, like a bundle of plutons, as in Figure 13a, or a unique root feeding different chambers, as in Figure 13b.

The isotope signals show that it is a mixture of mantel and melted crustal material. The granites of the Fichtel Mountains are also found together with other volcanic rocks, which span from grano-diorites (Redwitzite), to diorites to gabbros, which is magma originating from the mantel.

Next we visited the Steinbrücke Quarry near Bad Bernek, where pillow lavas can be seen in the low metamorphic rocks of the Münchberg Complex. The quarry is positioned in a fault zone not far from the Franconian Lineament. In the Ordovician, rifting at the rim of Gondwana created a micro-continent. In the Devonian, the continental margin sedimentary basin was intruded with basalt forming these pillows. It is not mid-ocean ridge basalt, in which case the setting would have looked more like the one in Figure 14. Instead, the Devonian pillow lavas at Steinbrücke were trapped during Variscan orogeny and faulted (Fig. 15).

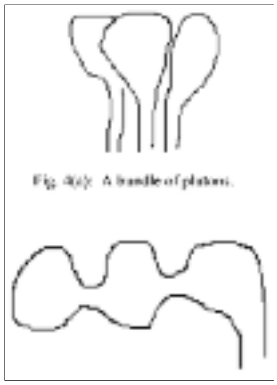


Figure 13 Alternative forms for the granite intrusions at Schurbach: (a) a bundle of plutons; (b) a unique root feeding different chambers.

We continued our journey northwards to the Münchberg Nappe Complex, which has been enigmatic since its discovery some 200 years ago. The metamorphic gradient is reversed, with high-grade metamorphic rocks lying on top of low-grade metamorphic rocks.

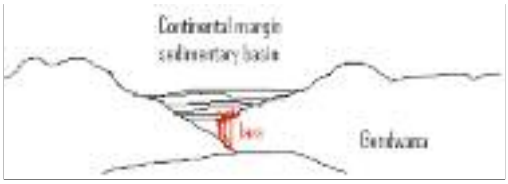


Figure 14 More typical Devonian pillow lavas.

Figure 15 Pillow lavas at the Steinbrücke Quarry.

There are four nappes in the Münchberg Complex. The upper unit (4) was laid down under ductile thrusting conditions, at a temperature of > 400°C. The lowest level of metamorphism is found in unit (1), prasinitic phyllite, with evidence of highly brittle thrusting. The intermediate units (2) and (3) also display thrusting under low temperature, brittle conditions. Below the four nappes, there is a unit known as the 'Bavarian (Bayerische) facies' (Fig. 16).

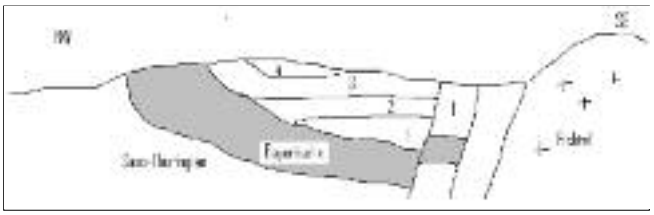


Figure 16 Diagram of the Münchberg nappe complex.

The brittle-to-ductile transition across the thrusts is not easy to explain. The thrusts took place during different events, in different time intervals and from different directions. There has been a 200-year discussion about the timing and setting of the sequences, which is still going on.

Not only was each unit transported in a different direction, but they were also deformed at different stages. The Münchberg Nappe is a 'klippe', as there is no connection to the root.

We stopped at the place called Hohenknoden where the contact between the brittle and ductile thrusting is exposed. Figure 17 *(opposite)* shows approximately what we could observe at this location and where we can assume the thrusts would be.

The brittle shear zone has a lenticular structure called 'phacoliths', which indicates intensive brittle shearing and thrusting under cold deformation conditions (Fig. 18, *opposite*).

Our last stop of the day was Weissenstein, where the highest grade metamorphic rocks of the Upper Unit, eclogite, are exposed at the south-west corner of the Münchberg Complex. The eclogite is composed of green clino-pyroxene (omphacite) and red pyrope garnets. It was formed at *c.* 600°C and 20kbar —

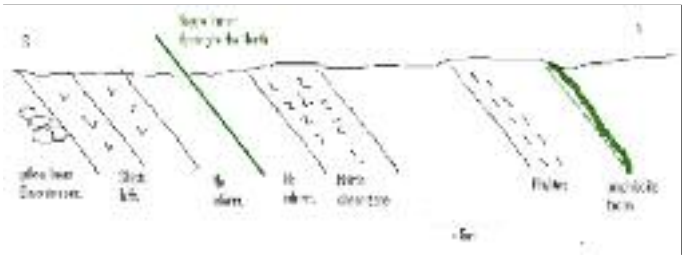


Figure 17 The contact between the brittle and ductile thrusting at Hohenknoden.

Figure 18 The contact between the brittle and ducile thrusting at Hohenknoden.

or 2GPa, that is, at a depth of *c.* 70km. The age of the metamorphism is *c.* 390Ma. The extremely high pressure and moderate temperature are characteristic of a subduction zone, where cold oceanic crust is subducted. Clearly, this rock was formed in a very different environment than the continental shelf sediments of the underlying Bayerische Facies of the Saxothuringian Unit.

Sample collection right at the Geosite is not allowed, so the group walked to an exposure that was outside of the prohibited zone, where Dr Rohrmüller still had enough strength to hammer rock samples off the exposure for all participants — and very impressive they are. That was the end of the day! And what a day!

Day 3 (27 October 2010): The Cheb Basin

Elisabeth d'Eyrames (text) and David Kopsch (photos)

Day 3 took us into the Tertiary sedimentary Cheb Basin, the yellow coloured region marked 3 in Figure 19. The basin is intracontinental, and its sediments were predominately deposited during the Neogene. The basin is situated at the south-west end of the Eger Rift Valley, or Graben, where it is delineated from the Eger Graben by a major shear fault known as the Mariánské Lázně or Marienbad fault. A number of small volcanoes are located along the western fringe of the basin. These were described as 'pocket' volcanoes by Dr Peterek. (Note: Eger is the German name for the Czech town of Cheb; the Czech name of the River Eger is Ohře.)

Figure 19 also shows the position of the KTB, the Franconian Lineament (which we had visited on Day 1) and the Duppauer Complex (which was visited on Day 4; *see below*).

Figure 19 Geological map of the Eger Graben (© Geopark Bayern-Böhmen — with kind permission).

We started Day 3 by driving from Windischeschenbach to Neualbenreuth, where we stopped some 50m from the Czech-Bavarian border, which we crossed by foot in the bright, misty morning light, into a nature reserve. The old border post, about the size of a garden shed, was still standing next to the footpath. The path took us to a cinder or scoria cone, formed during the middle to late Pleistocene, 300,000 to 500,000 years ago according to radiometric dating. However, some volcanologists think that it is no older than 100,000 years. Either way, it is the youngest volcano in north Bohemia, and is known as Železná hůrka or Eisenbühl (Iron Hill).

The study of the porosity of the scoria hints towards a first stage of pyroclastic events, followed by phreato-magmatic or hydroclastic events involving ground water and less gases (Fig. 20). As such, less porosity is visible in the phreato-magmatic scoria than that produced during the pyroclastic events. It was followed by explosive events, creating a large crater surrounded by scoria, called a 'Schlake' in German. The diameter of the volcano is *c.* 200m, and the material that was thrown out is mantel basalt.

Figure 20 Železná hůrka or Iron Hill scoria.

When this area was geologically mapped, more volcanic material was discovered 1km from the crater and the use of magnetic and gravity anomaly measurement identified a nearby depression, as a 'maar'. This name relates to the outcome of a phreato-magmatic eruption when the magma on its way up encounters groundwater. The distribution pattern of the volcanic material lead geologists to consider that there are more volcanic pipes aligned in a trend parallel to the Marienbad fault.

After Cheb we stopped next at a small, but famous volcano, the Komorní hůrka or Kammerbühl. It forms a gentle hill, some 50m high, on the Cheb Basin, which is *c.* 450m above sea level. Komorní hůrka is a cinder cone of lapilli — lava fragments of a few millimetres to a few centimetres in size, depending on the classification, for when they are larger they are called scoria (Fig. 21). The eruption started at the end of the Tertiary to the beginning of the Quaternary, with strombolian activity, and lasted into Pleistocene 115,000 to 15,000 years ago. The local wind pattern blew most of the pyroclastics to the east. At the final stage, lava filled in the

Figure 21 Komorní hůrka or Kammerbühl.

chimney and the crater, eventually flowing over the cone towards the south-west. Some of the last outbreaks happened during the Holocene, that is less than 10,000 years ago. The lava is a nephelinite, quite a rare basalt in Europe. The lapilli and the basaltic lava flow have been quarried since the Middle Ages; for example the black tower of Eger Castle is made of it.

The importance of this site is historical. It was at the heart of a controversy in the 19th century, when naturalists started to question the origin of this hill. The Neptunists (Neptune is the Roman sea god) thought that the basalt precipitated from the water as a sedimentary process. The Plutonists (Pluton is the Roman god of the interior of the Earth) defended the theory that basalt is the product of melting of brown coal, which erupted on the surface.

J. W. von Goethe was not only a romantic poet, but also a passionate naturalist, and as such visited the site in 1808. He first felt that the Plutonists had a point, but later he changed his mind. He persuaded Kašpar Šternberk, one of the founders of the National Museum in Prague, to take part in a research project, digging a gallery through the hill to prove that it is a volcano. They started in 1826, excavated 300m of galleries and found the chimney, but by that time Goethe had died. The galleries have since collapsed, but the portal of the old tunnel with its epigraphs can still be seen.

From Komorní hůrka we drove to Františkovy Lázně or Franzensbad, a spa town 10km north of Cheb, still at the western margin of the Cheb sedimentary basin (Fig. 22). We tasted the waters from different wells: Nový Kostelni, Glauber III and Glauber IV. Glauber IV is the most mineralised water in the Cheb Basin (*c*. 21g^{-l}), it has a carbon dioxyde content of 1.5g^{-l} and flows at a rate of 0.9 l^{-min} from a depth of 93m. Extremely healthy if not the tastiest of waters!

Figure 22 Františkovy Lázně or Franzensbad.

We also visited some of the other mineral springs in the park — there are more than 20 listed wells in Franzensbad. Why is there so much healthy water? The answer to that question is related to the tectonic structure of the sedimentary basin. An active magma reservoir in the upper mantel, at a depth of *c.* 30km, releases carbon dioxide and mantle fluids, which get trapped in the crust at a depth of 5–10km. Above this, in the upper crust, water–rock interaction releases minerals into the water, and eventually peat adds the extra taste.

After having 'taken the waters' and had a walk through the town, we made our way to Soos, 5km north-east of Franzensbad. Soos is a nature reserve in the central part of the basin. The basin is asymetrical in depth, which increases eastwards, to *c.* 350–400m at its eastern margin along the Marienbad fault (Fig. 23).

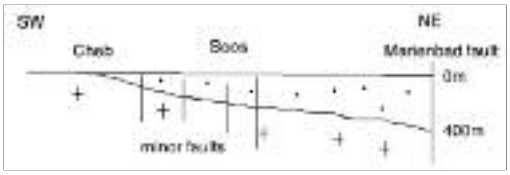


Figure 23 A cross-section through the Eger Graben.

At lunchtime the sun was warm enough for us to sit in the park-like entrance to eat our packed lunches. We then took a pleasant stroll on a boardwalk, through the nature-protected area of 'Soos'. This comprises a partly drained swamp, displaying diatomites up to 8m thick, from the early Holocene, and spectacular mofettes (gas emitting holes) with intense CO_2 emanation, derived from the upper mantle (30km depth) (Fig. 24). (Note: *The Oxford Dictionary of Earth Sciences* defines a diatomite as: 'A diatom- or bacillariophyceae-algae-rich sediment which has been laid down in a lacustrine or deep-sea environment. The diatom cell wall is made of silica, therefore, the sediment is siliceous.')

Figure 24 Mofettes in the Soos nature reserve.

In the whole of the Cheb Basin, there is a high concentration of degassing, aligned with the trend of the Marienbad fault; the gases find their way up along minor faults cutting through the sedimentary layers. How do we know the source of the gases? Measurements of the abundance of helium isotopes are made, He^3 has its origin in the mantel, whereas the crust is richer in He^4. Although the helium content of the gases is very small, the ratio of He^3 to He^4 is a good indicator of the source. When the He^3 : He^4 ratio increases, strong mantel degassing is indicated. The Cheb Basin has the highest He^3 : He^4 ratio in central Europe, similar to the ratio found in the region of Mt Etna. The question of continued subsidence of the basin is still under discussion; there might be some, but it is insufficient to account for further deposition, hence some erosion is taking place.

Our next stop was Nový Kostel, the epicentre of the north-west Bohemian swarm earthquakes, related to the Marienbad fault. Records of seismic activity go back to the 14th century, although not a lot of damage is associated with these earthquakes. After the tremors up to 4.6 on the Richter scale during the winter of 1985–6, intensive investigation of the area was launched. Among various techniques used is paleoseismology, which consists in digging trenches to study soil disturbances. In 2008, 40,000 events were recorded over a period of two months. Three-dimentional plotting of the centre of the seisms shows a curved fault plane. As the stresses in the crust are not released in a major event, but through thousands of minor quakes over several

weeks, the phenomenon is called an 'earthquake swarm'. Usually earthquake swarms occur next to a boundary where two tectonic plates meet, but here, that is not the case. It is more likely to be continuing magma injections into the crust, due to continuing rifting, that increases the pressure of the CO^2 trapped in the rocks, which triggers the earthquakes at a depth of 6–14km.

The highlight of the day was the Big Mofette south of Milhostov. This is the most beautiful and largest mofette of the Cheb Basin, and is called 'Bublak', or the 'bubbling spring' (Fig. 25). It is located in a swampy area in the valley of the Plesna River, which, according to Dr Peterek flows along an active fault, oriented NW–SE. A related fault scarp is indicated by the difference in the height of the flanks of the valley and asymmetry of the valley cross section.

Figure 25 Bublak, the 'bubbling spring'.

Twice a month the gasses are sampled and the isotopes checked. The idea is to get data that relate the variations of the isotopic ratio with the seismic activity, implying sampling before and after the tremors. Such direct measurements are difficult to carry out, as they can only be done by wading through the swamp in wellington boots. More recently, remote measurements can be made, but the results to date are not very satisfactory. There are also dry mofettes in this area — they can be located where the carcasses of dead animals are found, and are dangerous places to hang about.

To finish the day, we took a walk on the Litov mine tip close to Chlum Svaté Maří or Maria Kulm, where we found samples of brown coal and tempered shales (Porzellanite, Porcellanite) resulting from subsurface fires. The tip also provided a good view across the Eger Graben with the Krušné hory'or Erzgebirge to the north and the Slavkovský les or the Kaiserwald to the south.

Day 4 (28 October 2010): Loket and surroundings in the Eger Rift Valley

Fred Owen

A short, brisk walk from the hotel over the bridge crossing the River Eger took us to a grand exposure of the basement Karlsbad Granite, exhibiting huge plagioclase phenocrysts. Some displayed clear twinning (Fig. 26).

Below us, on the river bank, was an open-air auditorium and opposite stood Loket Castle, perched atop the same granite (Fig. 27). It had been built inside the loop of a huge meander cut *c.* 100m into the granite. How had it managed to cut so deeply into such tough rock instead of into the softer sediments?

Figure 26 Twinned plagioclase phenocrysts in Karlsbad Granite.

Andreas explained that this could only be the case if the Eger had first cut through the soft sediments and *then* into the granite beneath. Subsequent faulting of the granite and erosion of the soft sediments left the river in its present granite bed, as shown in Figure 28.

Figure 27 Loket Castle.

We next moved on a short distance to the lookout point over the massive Družba Open Cast Lignite (brown coal) Pit, Nové Sedlo shown below (Fig. 29, *overleaf*). Production started in 1642 and reached its peak output of 23 million tonnes^{-yr} in 1983. The mine covers *c*. 50 sq km and is easily identified on satellite images.

The Tertiary deposits lie in an east–west-oriented basin bounded to the north and south by tectonic faults. The lignite lies beneath 200m of overburden (seen in the spoil heaps at the end of Day 3) comprising clay and lake sediments of the Cypris Lake Formation. This overburden contains Late Miocene *Ostracod angulata*, and volcanic ash of the Chodov Formation. Parts of both these sediments are used as raw materials for making ceramics and absorbents.

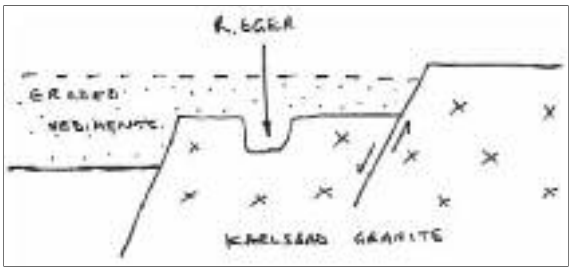


Figure 28 Sketch diagram showing how the River Eger incised the granite.

There are two main lignite beds of Oligocene age: the lower, Josef seam (which is 22m thick and dated 24Ma), and the upper, Antonine seam (which is 24m thick and dated 22Ma). The Antonine seem is presently being worked. The whole sedimentary pile is underlain by granite and igneous extrusives. Mining operators take great care not to penetrate the water table below, which feeds water to the Karlsbad health spas. Production is planned to continue for another 20 years before the whole mine will be flooded to form a massive recreational area.

From Družba our journey continued to the Erika Sand Quarry at Lomnice. This extensive quarry comprises 22m thick beds of the Staré Sedlo Formation, a sequence of Tertiary, fluvial and shallow lake sediments showing laminar and trough cross-

Figure 29 Družba Open Cast Lignite (brown coal) Pit, Nové Sedlo.

bedding, palaeochannels and graded-bedding. Erika is an internationally recognised locality for Late Eocene flora. We found numerous excellent leaf and plant stem fossils, such as the cinnamon leaf shown in Figure 30. The fossil flora found at Erika represent a subtropical environment similar to that found in present-day Vietnam, comprising laurels, palm fans and the precursor to oak. Goethe himself collected many plant fossils here.

These Late Eocene sediments are the oldest in the Eger Graben, but are topographically higher than the youngest lignite bed seen earlier. This apparent anomaly is due to a vertical 400m fault displacement post-dating the Cypris Formation. The Late Eocene sediments contain no carbonaceous material, and were formed during a period of global warming caused by the CO_2 produced by the major volcanic activity contemporaneous with forming the Deccan Traps at the end of the Cretaceous.

Figure 30 Cast of a fossil cinnamon leaf from the Erika Sand Quarry at Lomnice.

The sediments are from the Teplá Barrandian metamorphic belt to the south-east in central Bohemia, and from farther south. They were carried north through the Leipzig Basin and on to the palaeo-North Sea coast in large braided, meandering rivers, many running parallel to the original one. From May to August the deposits are the home of a colony of sand martins, which bore tunnels deep into the quarry faces to nest (Fig. 31).

Figure 31 A face of the Erika Sand Quarry, showing some tunnels of sand martins' nests.

After a short drive, we climbed a steep outcrop of quartz/plagioclase-rich rhyolite to reach a medieval castle atop Andělská Hora (Angel's Mountain) (Fig. 32). This is one of several rhyolite complexes to the south and south-east of Karlovy Vary (Karlsbad) and is associated with extension during the Eger Graben evolution. To the north-east a major source of magma was Doupov (Duppauer Gebirge), a volcano similar in size to Mt Etna. It stands east of Karlsbad and is the second largest stratovolcano** in Europe. It was active between *c.* 35Ma and 25Ma. Doupov lies within the Eger Graben and these rhyolitic exposures are scattered between the ENE–WSW rift boundary faults of the Graben. (Note: In a recent paper (in English) Frantisek Holub *et al*. say that the current indications are that the volcanic complex is made up of a cluster of shield volcanoes rather than a single stratovolcano. Holub, Frantisek V., Rapprich, Vladislav, Erban, Vojtech, Pécskay, Zoltán, Mlcoch, Bedrich and Míková, Jitka 2010 'Petrology and geochemistry of the Tertiary alkaline intrusive rocks at Doupov, Doupovské hory Volcanic Complex (NW Bohemian Massif)'. *J Geosciences* **55**, 251–78; also at www.jgeosci.org/content/jgeosci.074_2010_3_holub.pdf.)

Figure 32 Medieval castle ruins on Andělská Hora or Angel's Mountain.

As we looked south we could see a gently dipping planation surface, which truncates against the Slavkovský les or Kaiserwald. The Erzgerbirge range forms the northern margin of the Eger Graben, the highest peak being Keilberg (1,244m). The western margin of the Eger Graben abuts the NWN–SES Mariánské Lázně Lineament seen on Day 3. Thus, our view was of the landscape in the north-western corner of the Eger Graben. Figure 33 shows a picturesque view from the castle, through one of its remaining arches.

Figure 33 South dipping planation surface, as seen through one of the castle arches.

We were privileged to take lunch in the surroundings of Teplá Monastery, founded in 1193 by a nobleman who was beatified in 1897. The monastery houses a famous library of rare 15th-century books and a substantial collection of minerals. The Czechoslovak People's Army occupied it for 28 years from 1950 to 1978, during which time its condition deteriorated badly. It is now undergoing extensive renovation (Fig. 34, *opposite*).

As we toured the grounds I could not resist taking a photo of an augen gneiss in the wall near to the main gate entrance (Fig. 35, *opposite*). Our leaders did not discuss this stone. but presumably it is from the Teplá Barandian metamorphic belt.

Figure 34 Tepla Monastery.
Figure 35 Augen gneiss in a stone wall, Tepla Monastery.

Figure 36 Dr Andreas Peterek with a statue of J. W. von Goethe.

Figure 37 Marienbad, water-music display.

The Mariánské Lázně or Geopark was the final geological locality visited with Dr Peterek — an ideal place to take a photograph of Andreas and his friend Goethe (Fig. 36).

Marienbad geopark lies on the south-western slopes of Zizkov Hill and forms part of the Marianbad Museum. Along a 1.5km circular walk there are numerous exhibits of large cut and polished boulders of a wide variety of igneous and metamorphic rocks representing the nearby geology. All show clearly the features selected for each location, be it the crystalline fabric of the rock or its structure. Alongside each rock is an explanation board describing the formation and source of the rock, and features to be examined. The park also has a charming water-music display (Fig. 37), so after taking spa water at the famous colonnade and a relaxing coffee in the square we watched and listened to the singing fountain of its display to music.

Book review

Rothery, David A. 2010 *Geology: The Key Ideas*. London: Hodder (Teach Yourself Series) (ISBN 978-1-44410-312-0; paperback, 334pp; £10.99

As a newcomer to geology, I was interested in a book that offered a basic introduction to the field. I saw myself as a member of the target audience, and I was interested in finding out how 'The key ideas' would be presented.

The author himself , on page 1, describes *Geology – The Key Ideas* as "an introductory book".

The modern-looking cover image suggests that the book is a product of the 21st century, and it proclaims that the book is 'packed with images and diagrams'. This is indeed the case: the text is generously supported by many helpful diagrams and some black and white photographs, together with a small set of colour plates grouped together in the middle of the book. As additional aids to the student, there are 'insights' in boxes throughout the book, and a helpful summary of 'Things to remember' at the end of each chapter.

The book focuses on geological processes and is organised around the rock cycle, with additional material, such as an initial description of the composition of the earth, a final chapter on fieldwork, an index and a useful glossary. The 334 pages cover a broad field of knowledge and the book is inevitably quite condensed (for example, the study of fossils, including the history of life and the use of fossils in geology, is covered in 24 pages in chapter 12); and yet it is accessible even to a beginner.

The author skilfully builds the reader's understanding, advising the reader, on page 3, to read sequentially because of the introduction of technical terms. Moreover, only a basic level of scientific knowledge is necessary to tackle the book. The embedding of the essential science within the book works well, although readers with little or no scientific knowledge may find that some concepts, such as the chemical composition of minerals, need further explanation.

Is there anything that I would like to change about the book? Well, this is the most recent edition of a book that was first published in 1997. Inside the modern cover, while the text is legible and the diagrams are clear, some of the black and white photographs are lacking in detail — possibly due to the printing technology. Indeed, a few of these, for example the photograph of Staffa on page 78, are difficult to decipher. This is a minor point, however.

Overall, this book is an excellent introduction to the field!

— Sandra Morgan, interested amateur, MA (English Language), PhD (Email discourse)

Book review

Rothery, David A. 2010 (2001; rev 2007; expanded 2010) *Teach Yourself Volcanoes, Earthquakes and Tsunamis*. London: Hodder Education (ISBN – 978-1-44410-311-3; paperback, 362pp; £10.99)

Having grown up to recognise the distinctive yellow and black jackets of the small hard-backed 'Teach Yourself' books, the cover of this paperback version is fresh and informative. On the front is a summary of the contents with page numbers, and on the back a panel with highlights.

The ten chapters describe earth movements and eruptions, volcanic types, hazards, climatic effects, monitoring and living near volcanoes, earthquakes, prediction, preparedness and tsunamis.

This 2010 revision of the 2001 edition comes in the wakes of the 2004 Indonesian tsunami, and the 2010 Haitian disaster and Icelandic ash cloud, but before the destructive New Zealand earthquakes of September with subsequent and continuing events in Christchurch. This last has involved a large amount of liquefaction, also extensive damage to the 'heritage' area of the central city; and tremors above 5 are still being experienced as at 8/2011.

Following the expanded list of contents comes a set of Roman numbered pages, entitled "Meet the author", "Only got a minute?", "Only got five minutes?", "Only got ten minutes?", involving a brief and cumulative introduction to the book. At intervals throughout the book there are bordered pages of "Things to remember" and small 'insight' panels expanding or commenting on a previous topic. There are plentiful clear diagrams, figures, tables and illustrations, also relevant monochrome and colour photographs, many taken by the author.

At the back of the book, "Taking it further" includes a list of websites, followed by a very useful Glossary and a comprehensive index, although neither contains a reference to 'liquefaction'. It is mentioned in chapter 10 "Living with earthquakes", but when I tried to find more about it, I was disappointed.

Otherwise, I found the book full of fascinating facts, both for people knowing nothing, and for others knowing a good deal about the subjects. Some topics are presented with a different approach, bringing a freshness to these topics. It is a book I would recommend and of a good size for the rucksack.

— Rosemary Darby, BA(Open); BSc Hons (Open) (Earth Sciences); Certs Ed (UK and NZ)

An introduction to the seamount stage of development of La Palma, Canary Islands and a guide to its exposure in the Barranco de las Angustias

Duncan Woodcock (OUGS NW, duncan.woodcock@hotmail.co.uk)

Introduction

Ocean islands, such as the Hawaiian and Canary Islands, are manifestations of intra-plate volcanism, driven by a melting anomaly below (or within?) the lithosphere. The 'seamount' stage of development of an ocean island involves submarine volcanism within increasingly shallow water as the products of volcanism, principally pillow lavas and volcanic breccias, accumulate. Once emergent, magma is increasingly isolated from contact with water and the 'shield building' stage is characterised by voluminous lava flows that make up the bulk of a typical ocean island above sea level. Over-steepening of the resulting volcanic edifice often leads to collapse: thus the subaerial development of ocean islands is usually characterised by cycles of growth and collapse.

This paper is principally concerned with the 'seamount' stage of development, particularly that of La Palma, where it is well exposed in an erosional inlier in the centre of the island.

The 'seamount' stage

On an island in the Canary archipelago, exposures of the seamount stage of ocean island development are usually described as part of a 'basal complex' that is separated from the products of the overlying subaerial stage by a major unconformity. An 'ideal' basal complex would contain the following components (Carracedo *et al.* 2001):

• a sequence of oceanic sediments, associated with ocean floor basalts, which together comprise remnants of the pre-existing ocean floor;
• a thick sequence of submarine volcanic rocks, showing a progression from a deeper-water facies with a predominance of pillow lavas to a shallow-water facies dominated by tuffs and breccias;
• a basaltic dyke swarm — the feeder dykes to the complex and to the overlying subaerial stage; and
• a plutonic complex, comprising mafic and ultramafic intrusions.

Basal complexes crop out on three of the Canary Islands, where the vagaries of erosion have exposed the various components to different degrees (Fig. 1). On Fuerteventura there are exposures of a sequence of uplifted and deformed ocean crust and sediments, together with extensive exposures of the plutonic complex, in the western mountains (Woodcock 2000). A plutonic complex is well exposed in the north of La Gomera (Woodcock 2004). In contrast, on La Palma the plutonic complex is relatively poorly exposed, but a thick sequence of volcanic rocks is exposed in the Barranco de las Angustias — a deep ravine in the centre of the island. The development of this unusually deep barranco is a consequence of the cycles of growth and collapse during the early subaerial construction of La Palma and can be best understood by a brief look at the geological history of La Palma.

Overview of La Palma geological history

Table 1 (*page 35*) summarises the geological development of La Palma (Fig. 2). A Pliocene seamount stage (considered in more detail below) was followed by a period of uplift, tilting and erosion. The subsequent subaerial development shows the typical cycle of growth and collapse of a volcanic edifice (Carracedo *et al.* 1999). Subaerial volcanism began in what is now the north of the island with the growth of the Garafia volcano. This volcano was partially destroyed in a giant landslide and the Taburiente volcano developed within the collapse embayment. The Taburiente volcano in turn was partly demolished in the Cumbre Nueva collapse, leaving a collapse 'caldera' that formed the nucleus of the present-day Caldera de Taburiente (Fig. 3, *overleaf*).

A new volcano then developed within the collapse embayment. This volcano, known as the Bejenado volcano, grew rapidly and confined the drainage pattern to the north-west wall of the embayment, resulting in intense local erosion. The resulting Barranco de las Angustias is much deeper than other barrancos on the island: it has cut right through the northern flank of the Bejenado volcano

Figure 1 Sketch map of the Canary Islands. Basal complexes are exposed on Fuerteventura, La Gomera and La Palma.

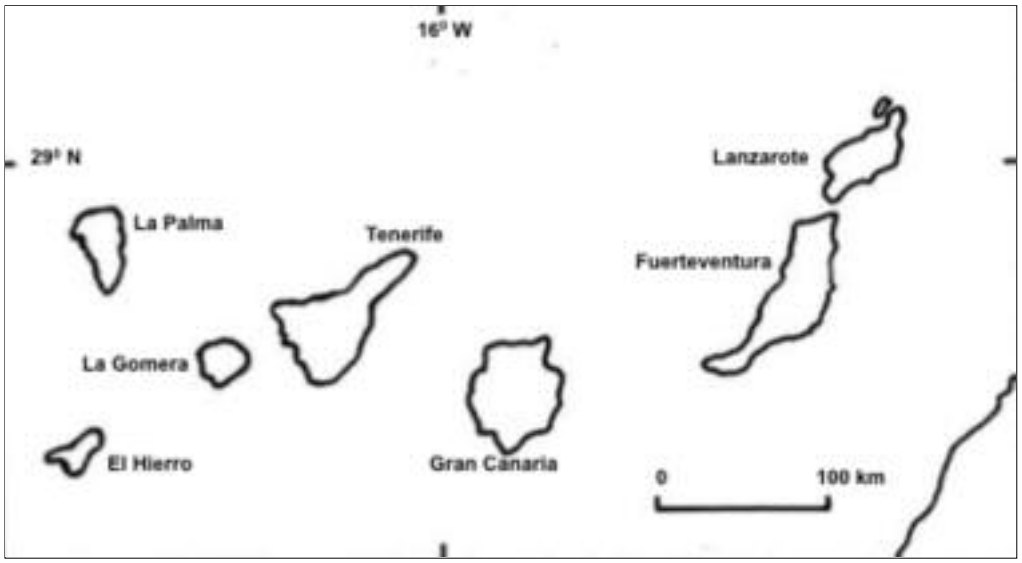


Figure 2 Sketch map of La Palma, showing locations mentioned in the text.

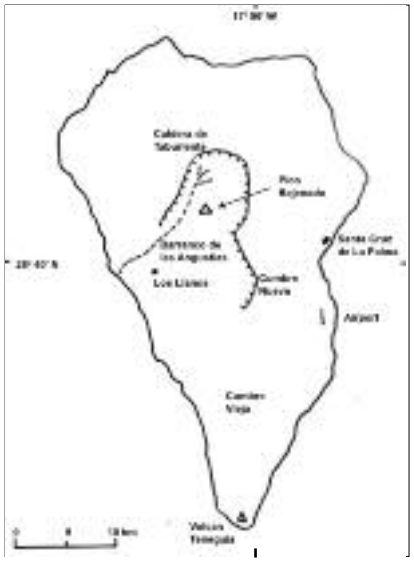


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Figure 3 The northern wall of the Caldera de Taburiente with Pico Bejenado, the remnants of the Bejenado volcano, in the middle distance.

and down into the seamount series. The products of erosion were transported seawards and deposited in a large fan delta known as the El Time Formation (Carracedo *et al.* 2002). The shallow-water facies of the El Time Formation is exposed in the lower reaches of the Barranco de las Angustias (Fig. 4).

Subsequent volcanism on La Palma has been concentrated in the south of the island along the Cumbre Vieja ridge, where six eruptions have occurred in historic times. The most recent activity was the eruption of Volcan Teneguia in 1970 (Woodcock 2008).

Figure 4 Sedimentary sequence from the El Time Formation — Location A on Figure 12. The lower conglomerate unit contains thin lenses of sandstone that attest to periods of slacker water. The upper sandstone unit contains thin cross-bedded and rippled units that indicate deposition in shallow water.

The seamount stage on La Palma

The Barranco de las Angustias exposes a 3.6km thick sequence of pillow lavas, hyaloclastites, dykes and plutonic bodies of the seamount stage. The sequence has been tilted 50° to the south-west; the barranco thus runs approximately along dip, exposing progressively shallower facies as one progresses downstream. An early geological description of the sequence was produced by Hernandez-Pacheco (1971). Hubert Staudigel carried out a more detailed study as part of his PhD thesis (Staudigel and Schmincke 1984).

The plutonic complex is poorly exposed on steep terrain and access is difficult within the confines of the Caldera de Taburienta National Park. Fortunately, the bed of the barranco downstream of the Park boundary is littered with pebbles and boulders of the wide variety of mafic and ultramafic material eroded from the plutonic complex.

The volcanic sequence of pillow lavas and breccias is well exposed in outcrop in the barranco. The deeper-water facies comprises predominantly pillow lavas (Figs 5 and 6, *opposite*) and subordinate breccias with many exposures cut by one or more generations of mafic dykes (Fig. 7, *opposite*). The breccias are often 'pillow-fragment breccias' that contain recognisable 'pie slices' of broken pillows (Fig. 8, *page 36*).

The proportion of clastic material increases downstream as the products of a more explosive eruption within shallow water are encountered. The clastic material is predominantly hyaloclastite (s.l.): lapilli and ash that was once glassy but is now devitrified. This shallow-water facies also contains patches of 'pillow scoria breccia' (Staudigel and Schmincke 1984). These patches comprise amoeboidal, highly vesicular pillows and stringers of lava (Figs 9 and 10, *page 36*), thought to be formed by cracking and bleeding of gas-rich pillows.

Figure 5 Pillow lavas — Location F on Figure 12. Field of view 3m × 2m.

Figure 6 '2.5D' view of pillow lavas — Location E on Figure 12. Field of view 2m × 1.5m.

The whole extrusive sequence was hydrothermally altered after emplacement, with deeper-water units metamorphosed to greenschist facies. Boulders of green lavas in the lower reaches of the barranco have thus been transported downstream and the size of some of these boulders attests to the power of the stream when in full flow after heavy rainstorms. The metamorphic minerals tend to develop best in the inter-pillow spaces (Fig. 11, *page 36*).

A geological guide to the volcanic sequence in the Barranco de las Angustias

Brief geological guides are available in the literature (Duncan and Norcutt 1994; Carracedo and Day 2002). A more detailed but unpublished guide was produced by Hubert Staudigel for a field excursion that he ran some years ago; receipt of a copy of this guide is gratefully acknowledged.

Figure 12 *(page 37)* is a map of that part of the Barranco de las Angustias where the exposure is most accessible. The annotation on the map should render it largely self-explanatory. I have not included every exposure, only those that I consider to be the most spectacular or instructive.

The steep sides of the barranco upstream of the car park (Fig. 13, *page 37*) render a GPS practically useless. I used colour prints taken from Google Earth images to determine my position. The satellite imagery currently available on Google Earth from Grafcan is of such good quality that it can be enlarged to allow individual large boulders to be seen clearly. Figure 12 was developed from a set of Google Earth images, all at the same scale and with an orthogonal latitude-longitude grid superimposed to allow accurate overlap of adjacent images.

Within the barranco, outcrop occurs on both banks and it is necessary to repeatedly cross the stream. This presented no major difficulty during my visit at the end of March 2010 (after a relatively wet winter in the Canary Islands); however it may be difficult or impossible earlier in the year or after recent heavy rain.

Figure 7 Sequence of pillow lavas cut by three generations of dykes — Location G on Figure 12. Field of view 5m × 3m.

Table 1 Geological development of La Palma (adapted from Carracedo and Day 2002)

stage	*feature names and activities*	*dates*
shield-building stage	Cumbre Vieja volcano	120ka to present
(subaerial volcanism)	*erosion (deposition as El Time fan delta)*	
	Bejenado volcano	0.56Ma to 0.49Ma
	giant landslide (Cumbre Nueva collapse)	
	Taburiente volcano	1.2Ma to 0.7Ma
	giant landslide	
	Garafia volcano	1.7Ma to 1.2Ma
	uplift, tilting and erosion	
seamount stage		
(submarine volcanism)	intrusive complex and dykes	
	extrusive: pillow lavas and volcaniclastics	Pliocene (3–4Ma)

Figure 8 Pillow-fragment breccias — Location B on Figure 12. Note that the chilled margin is restricted to the original outer surface of the pillow (cf Fig. 10).

Figure 10 Close up view of amoeboidal pillows at Location D. The chilled margin, comprising a light-weathering devitrified glass, completely surrounds each fragment (diameter of coin 20mm).

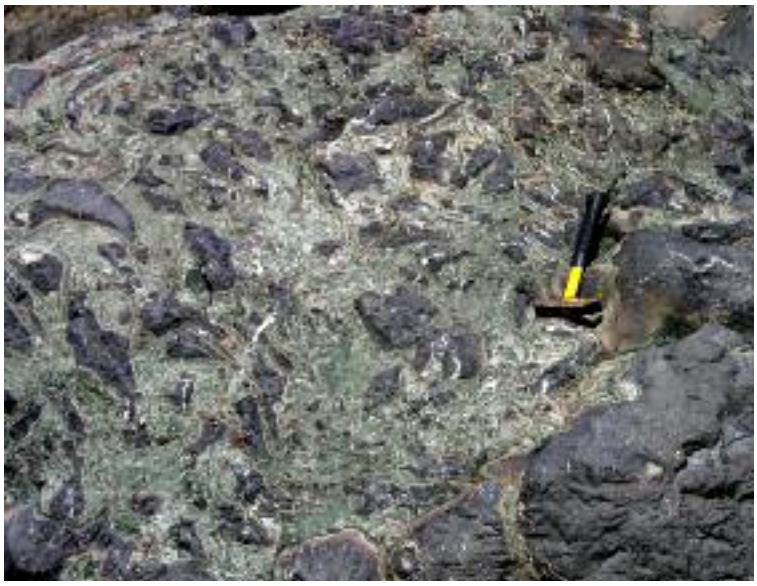

Figure 9 Exposure of amoeboidal pillow lavas immediately above a 'normal' pillow lava exposur — Location D on Figure 12.

Figure 11 Interpillow space filled with epidote — Location C on Figure 12 (diameter of coin 20mm).

There is ample space to park vehicles in the barranco. Access into the barranco from the suburbs of Los Llanos is via a steep, narrow road with a multitude of blind bends. You may wish to time your visit to minimise oncoming traffic by descending early in the morning and returning late in the afternoon; this strategy has the additional advantage of giving one a long and instructive field day with a variety of lighting conditions within an outstanding location.

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Pillow lavas and dykes (Figure 7)
17° 54'W
Pillow lavas and dykes where path crosses barranco
Footpath
Heavily dyked area in steep cliffs
Pillow lavas on prominent bend in barranco (Figure 5)
Pillow breccias on two large boulders
Pillow lavas
Amoeboidal pillows
Pillow lavas in large boulder (Figure 6)
Pillow breccia
Amoeboidal pillows on boulder (Figures 8&10)
Large boulder of pillow lavas with interpillow epidote (Figure 9)
Pillow breccia (Figure 8)
Pillow lavas with interpillow jasper
Pillow lavas
Bridge
Track
Bridge
Pillow lavas
Ford
Car park
(6) Thin sediments (Figure 4)
Amoeboidal pillow lavas
0 100 200 300 m
17° 54' 00" W

Figure 12 Sketch map of part of the Barranco de las Angustias, showing a selection of exposures of the volcanic sequence of the 'seamount' series. The capital letters in box indicate locations of figures.

Figure 13 (right) General view of the Barranco de las Angustias.

Book review

Rothery David A. 2010 *Planets: A Very Short Introduction*. Oxford: OUP (ISBN 978-0-19957-350-9; paperback, 140pp; £7.99)

This little book is definitely multum in parvo: there is so much information and no padding. Measuring just 6.75 × 4.25ins (170mm × 110mm), it fitted easily in my pocket and kept me absorbed, entertained and informed on the long flights from London to Hong Kong and Auckland.

It is nicely set out with book title on the left and chapter headings on the right hand page edge. The print is clear and illustrations well annotated. The style is suitable both for scientists and non-scientists.

The Contents page lists illustrations and tables as well as chapter headings, together with a list for further reading and the index. Comments on publications for further reading include likely expectancy of future relevance of books, and a list of websites.

Chapter 1: The Solar System This chapter includes the very recent demotion of Pluto and its place with Eris in the 'Plutoid' trans-Neptunian dwarf planets (see chapter 6).

Chapter 2: Rocky planets discusses the four inner planets plus the Moon, as being geologically similar. The structure of each planet, its internal heat and volcanism are explained before separate examination, then surface processes and nomenclature, atmosphere and cycles.

Chapter 3: Giant planets looks at the composition, interior structures, atmospheres and magnetospheres of the four outer planets.

Chapter 4: Giant planets' satellites and rings This chapter includes examples from many space probes, both data and pictures.

Chapter 5: Asteroids discusses their composition and orbits, mostly between the orbits of Mars and Jupiter. The potential hazard of collision with Earth by asteroids crossing our orbit is estimated, also the tsunami/extinction effect. The informal 'Spaceguard' is noted for its importance in "locating and categorising all Potentially Hazardous Asteroids".

Chapter 6: trans-Neptunian objects (TNO) includes 'centaurs' between Jupiter and Neptune and six 'Trojans' of Neptune. Beyond Neptune is the Kuiper belt and all other TNOs, including the new dwarf planet, Pluto, with Eris, Make-make, Haumea and nine other 'large' objects; also the probability of more 'large objects' being found.

Chapter 7: Exoplanets covers 'extra-solar planets' found around other stars outside our Solar system. There is as yet little information about them, although with improving technology, knowledge is increasing. The chapter concludes with speculation on potential life-forms and intelligent life, with SETI having found nothing so far.

This book would be a useful addition to the library of any interested person. I enjoyed it very much.

— Rosemary Darby, BA(Open); BSc Hons (Open) (Earth Sciences); Certs Ed (UK and NZ)

The lead mines at Charterhouse in the Mendip Hills

Chris Popham (OUGS South-West)

Introduction

Mining probably began here during the Iron Age but became an industry within a few years of the arrival of the Romans. Archaeological evidence dates the Roman occupation at the site from 49 CE. A number of pigs of lead weighing up to 200lbs each have been recovered from Charterhouse clearly stamped to show their origin and with the names of emperors dating from 49 CE to 200 CE. Others similarly stamped to indicate they originated at Charterhouse have been found as far afield as Bath, Bristol and even The Somme in France. Pottery and coins abound and from the latter it is apparent that from *c*. 200 CE Roman influence at the site declined; but there are still a few coins right up to c. 410 CE, when the Romans finally quit Britain.

The Romans were not only interested in the lead, but also in the silver that may account for up to 0.4% of some lead ores. So they took firm control of the site and built a small fort intending to use the silver to pay soldiers' wages.

Britain was one of the prime sources of lead for the Roman Empire and the Mendips were one of the three main sites in Britain. Of all the historical lead mines on Mendip, Charterhouse, it seems, was the pre-eminent Roman site. They clearly planned to stay, and even built a small amphitheatre or gymnasium, the only one known to be associated with a mine in south-west England. However, the silver yield proved to be low and within a short time mine management had been transferred from the army to independent agents.

The Mendip Hills landscape

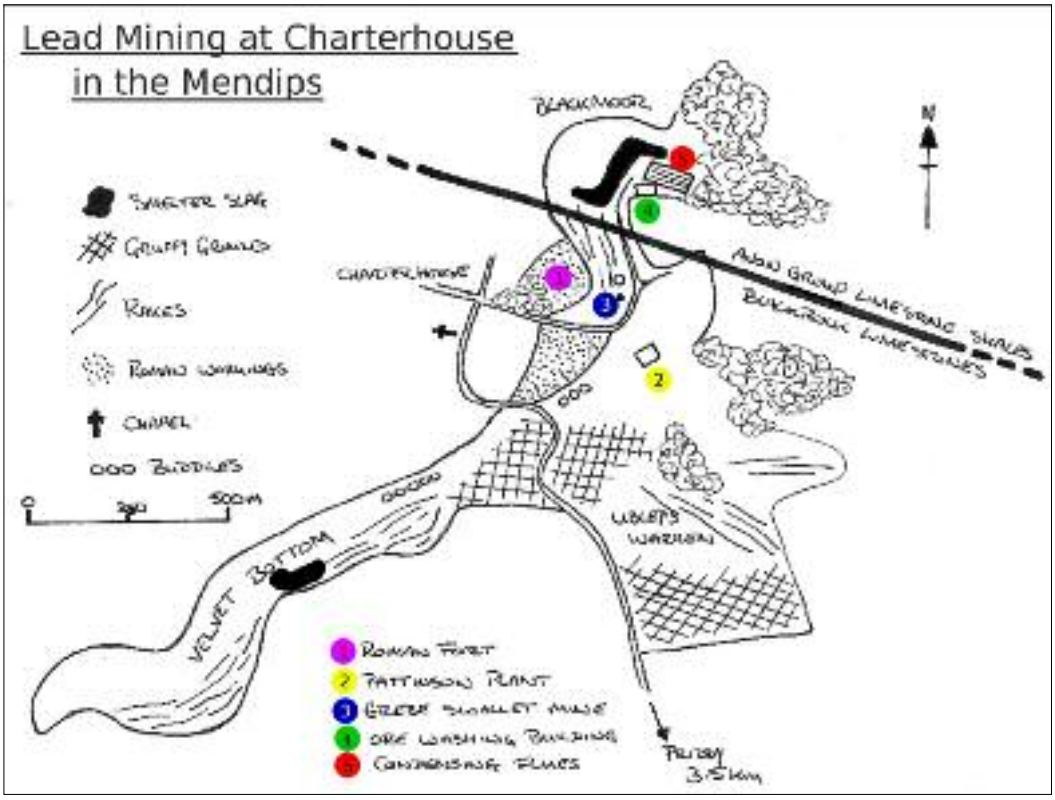
The Mendip Hills form a prominent north-west–south-east ridge through the middle of Somerset. This ridge stretches from beyond Shepton Mallet almost to the fringe of Sailsbury Plain in the east to Weston-Super-Mare on the Bristol Channel coast, though in the west the line of hills becomes very broken. The structure is a substantial anticline capped with Carboniferous Limestone, punctured in places by Old Red Sandstones and on the flanks are deep gorges choked with dolomitic limestone conglomerate eroded from above the present-day surface.

The mineralisation occurs as veins of loose rock, clay and calcite 'spar', with stones, granules and intergrowths of lead ore in fissures that follow the structures in the resistant Carboniferous Limestones. This neat packaging makes it possible to excavate the galena (the sulphide ore of lead) with great efficiency, leaving little in the excavation. The gulleys thus created are locally termed 'rakes' and at Charterhouse these are the Ubley's and Blackmoor Rakes. In addition to the rakes, the ground around is also disturbed with exploratory 'costean' pits, dug to find the strike of the lodes, and numerous rubble tips. Collectively the local term 'gruffy ground' is used to describe the resulting landscape.

Charterhouse site tour

To take a tour of the site, start from the parking place along the top of the road embankment (NGR ST503554) and walk up through the gruffy ground to a prominent rake on the crest of the hill in the south-east corner of the 'liberty', as the mining areas were known. The site is otherwise laid out along a shallow south-west to north-east valley stretching nearly 2km. From here a substantial part of the site can be seen, including a row of three 'buddles' close under the road embankment. This was where crushed ore was separated from powdered rock using running water. The overall layout of the site is shown in the drawing below (Fig. 1).

Figure 1 Site plan.



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The rake is several hundred metres in length, up to 20m in width and comprised a number of intersecting channels of varying widths, and up to 5m deep. Notably, however, the southernmost wall of the rake is sharp and nearly vertical, suggesting a fault plane with the beds in the rake dipping at about 25° south-south-east towards the fault. Some individual blocks of stone show random strike and dip, which may be a consequence of natural forces or settling after being undermined, as the blocks must weigh many tens of tons in some cases. The pale grey 'Black Rock Limestone' contains many crinoid fossils along with solitary *Caninia* and branching *Syringopora* corals, but no trace of any mineralisation.

Cross over the stile in the wall and walk down to one of the dressing floors and the site of the works where silver was refined from molten lead by the Pattinson process, a form of cupellation.

From this dressing floor you can follow the path to the small car park on the edge of the 'watercourse' and walk north-east along the track beside Blackmoor Rake, crossing over onto the Avon Group Lower Limestone Shales in the process, to see an area of differential drainage. The Roman fort and workings are set in the hillside below St Hugh's Church on the north-western side of the site.

Mendip mining processes

The Pattison process and early mining

The Charterhouse mined lead was melted in large iron bowls up to 1m in diameter and then left to cool very slowly while being constantly but gently stirred. In this way the lead solidifies in large crystals that can be scooped from the mass. The mixture is melted again and crystallisation repeated over a number of cycles until the silver content reaches about 2.5%. Zinc is then melted into the mix, the silver dissolves into the zinc, and this mix floats on the lead and thus can be scooped off. The zinc is then redistilled from the silver.

The advantage of the Pattinson process over older methods was that in the latter the lead was exposed to a stream of air, causing it to oxidise and form a worthless scum (litharge) that was raked off and discarded. In the Pattinson process oxidation is controlled and restricted to only a small fraction of what would otherwise occur. Purified lead recovered from the Pattinson process is also considerably more malleable than it would have otherwise been, thus making it suitable for sheet work.

Figure 2 Dipping beds and possible fault plane in Ubley's Rake.

The path from the dressing floor to a small car park along the 'watercourse' and track beside Blackmoor Rake crosses over onto the Avon Group Lower Limestone Shales. This transition is apparent in the water retentiveness of the ground: the areas of the watercourse underlain by Black Rock Limestone are well drained and do not hold running water in normal conditions, whereas numerous ponds have been created on the poorly draining Avon Group Shales. However, in 1968 an extreme rainfall event produced a torrent of water in the valley sufficient to sweep away the road embankment. More importantly, the water also found a way into a shallow depression on the eastern side of the valley bottom just onto the Black Rock Limestone and opened a sinkhole. This was excavated in 1981 and found to be Grebe Swallet Mine, extending underground towards Ubley's Rake as far as the Pattinson plant to a depth of 55m. In 2008 a blockage was cleared revealing a further 3.5km of cave passages to a depth of 220m, making it the fourth deepest cave in England.

Records from the 18th century in particular refer to, and in some cases describe, a number of huge caverns that were broken into during mining. But even by the early 19th century, when interest in the area was renewed, most of these could not be found. It is possibly the case, miners being miners, that these caverns were back-filled with waste rock, as it is much simpler to dump mining debris underground than to haul it to the surface.

Opposite St Hugh's Church, Ubley's Rake (Fig. 2) is on the opposing south-east hill, and the evidence of the 1968 flash flood, together with the layout of the site, perhaps show this to be an ideal location for the Roman practice of 'hushing'. Water would be held behind a dam until a sufficient head had been accumulated whereupon it was let go as a flood, scouring away topsoil and small rocks and stones, and thus revealing lodes *in situ* and also leaving behind the dense galena stones. Tin miners on Dartmoor were still using this technique in their open cast 'beams' until the 19th century, when underground mining through shafts put an end to the practice (Fig. 3, *opposite*).

Miners during the Roman occupation and those who followed in the Middle Ages had worked only close to the surface, finding that the lodes pinched out with depth. These early miners did not have the technology for deep mining. Such pinching-out is somewhat typical of ore deposits produced by metasomatic enrichment in soluble rock such as the Carboniferous Limestones. As the groundwater rises it dissolves the rock and fans out. In doing so it also alters from acidic to alkaline, which precipitates the metal minerals. In contrast, veins formed in the granite, typically along faults, tend to remain reasonably uniform and the minerals are deposited along a falling temperature gradient. Pinching-out is also seen in mines surrounding the granite masses, for example Wheal Exmouth in the Teign Valley, a typical example.

17th- and 18th-century mining

In the mid-17th century lead output from the Charterhouse mines was at its peak. Every man was able to stake a claim where he found a new outcrop of ore, and despite laws to prohibit it, even highways were dug away. In many cases the mines followed the ore veins, frequently taking advantage of the naturally occurring 'swallets' and pot holes, which made access difficult and dangerous. In places where the ground was harder the miners resorted to fire-setting to break up the boulders. This practice left the mine

Figure 3 View of St Hugh's Church and a prominent pericline beneath the masts on the horizon. Roman gruffy ground is on the far side of the valley, as well as medieval workings in the foreground.

unworkable for days, however, due to the heat and poor ventilation. Ventilation was as much of a problem as drainage was, and was achieved by putting up cowls on the surface to direct any breeze into wooden ducts to lead it down into the mine.

Water, despite being scarce on the surface where it was in great demand for ore processing, was a considerable problem beneath the surface. But 17th-century technology was not up to the task of draining the mines. Unlike many of the mines in Devon and Cornwall, which lie along river valleys where drainage is possible with adits, the Mendip Mines lie in the middle of a plateau. Some drainage could be achieved by taking water through adits into the natural swallets. However, because most Mendip mines were run by a few freemen working together, and because Mendip mining custom set very clear limits on the size of mines underground, draining with adits was often impossible.

Unable to reach the ore deeper in the mines, the miners stripped away every last vestige of the ore they could reach and by 1700 lead mining had ceased on the Mendips.

In the late 18th century plans were made to reopen the Charterhouse mines. Drainage technology had improved with the coming of the age of steam and Cornish miners had gained experience in finding deeper ores where lodes passed from country rock into the granite. This new knowledge no doubt explains why they began coming to the Mendips in the mid-18th century and began reviving the mines with deeper shafts. However, even though the deepest exceeded 55 fathoms (roughly equivalent to 100m), this depth was shallow compared to some Devon and Cornwall mines, which often exceeded 600 fathoms, sometimes even 800 fathoms. In any case, mineralisation in the Mendips veins was minimal below 50m and work was soon abandoned again.

Mining the early spoil heaps

Despite the failure underground the spoil heaps from earlier times were found to contain large quantities of galena, up to 55% in places. Early miners had apparently sorted out the galena stones by hand, taking only the easiest to find ore and leaving the loose grit and any disseminations in harder rocks. Setting up a very large reservoir at Blackmoor (on the site of a reservoir used by the Romans for hushing perhaps?), a network of leats, raised launders, at least one waterwheel, numerous buddles and a tramroad, these later miners were able to extract considerable amounts of lead (Fig. 4, *overleaf*). In addition, the previously smelted slag waste was found in some cases to contain up to 20% by weight of lead and a smelter was also set up at Blackmoor in the upper end of the valley to process this waste. It was during this reprocessing that much of the Roman archaeological evidence was found and simultaneously lost or destroyed. Many of the Roman lead artefacts, including whole pigs of lead, were simply melted down.

The first indications of the scale of these operations are the vast dumps of broken, glassy, black smelter slag, not at all unlike obsidian and still in some instances viciously sharp. These dumps are made up of golf-ball size pieces masses of these welded into cubes as much as 1m square. This wasteland extends several hundred metres and forms the tiered banks of the reservoir.

Figure 4 A pond at Blackmoor on the water-retentive limestone shales banked with glassy, black smelter slag.

Figure 5 Smelter flues at Blackmoor. It is just possible to make out orange lead oxide patches on the stonework.

The blocks must have been formed as the result of the slag pieces settling into the base of the furnace in such a way that they could be drawn out once cooled. Before reprocessing began at the Priddy Mine a few miles east of Charterhouse in the 19th century, one estimate put its potentially workable slag at 400,000 cubic yards, which would yield 500,000 tons of lead at £1 per ton. By all accounts a similar amount of material was available at Charterhouse.

A lead smelter was in operation for many years at Weir Quay on the Bere Alston Peninsula in Devon but there are no similar dumps at that site even though occasionally pieces of brown fused slag are found on the shoreline. This difference may reflect the fact that at Charterhouse there was a ready supply of the Black Rock Limestone that could be used as a good flux, whereas around Bere Alston the country rock is shale and mudstones, so the two sites produced different wastes.

The erection of such a large smelter at Charterhouse and others nearby, such as St Cuthbert's at Priddy, was probably also only possible because of the local source of coal in Somerset. In Devon and Cornwall coal had to be imported by barge around Land's End from South Wales, so it was more economical to send the ore to smelters in South Wales. Charterhouse miners similarly sent their ore by water via a port at Cheddar to a smelter in Bristol for the last 10 years of operation.

Galena smelting

The availability of coal in Somerset may also explain why there are no large slag heaps at Bere Alston. The smelter there may have been in use for a long time, but the throughput may have been limited to ore rich enough to recover its silver — thereby keeping the silver in the hands of the mine owners and not trusting it to the honesty of agents.

Galena is smelted in a two-step process. Initially it is roasted to produce lead oxides and sulphur dioxide gas. The solid oxides are then roasted with charcoal, coal or coke to produce a reducing atmosphere, giving lead metal and carbon dioxide. Smelting can be achieved with only low efficiency as a one step process, perhaps explaining why the wastes from early smelting operations still had a high lead contents (as oxide?). These wastes were later re-smelted — for some wastes this was the third time around — in the even more efficient 19th-century reverberatory furnaces.

In addition to the slag heaps there are the remains of a condensing labyrinth. This is not at all like the arsenic labyrinths seen in Devon and Cornwall ,where the fumes are made to zig-zag along their course, depositing metal oxides on the brickwork. At Charterhouse condensing was achieved in linear passages approximately 0.5m wide (just tall enough for an adult to walk in without bending), 100m long and open at both ends (Fig. 5). Lead oxides from the fumes condensed on the walls and were collected for reprocessing to recover the lead metal. This also reduced pollution and contamination of surrounding farmland. Nevertheless, local farmers brought a number of successful compensation cases against lead smelters, including at Charterhouse, where the mine company was forced to buy up nearby farmland.

Arsenic minerals are not found in the Mendip mines as arsenic mineralisation in the UK is only associated with the granite masses of Devon and Cornwall, and in Cumbria and Derbyshire. Consequently, there is no hint of the hexagonal, platy crystallisations of arsenic oxides on the stonework of the flues, so much a feature of these structures in Devon and Cornwall. There are, however, white and bright orange 'botryoidal' encrustations on the north-facing walls outside the arched over tunnel sections (Fig. 6). Modern analysis of some of the Roman lead pigs has shown traces of arsenic, gold, copper and antimony, but only traces.

Figure 6 Orange and white encrustations of lead oxides on the stonework of the smelter flues.

The oxides of lead are often collectively termed 'litharge', after the oxide scum formed during cuppellation. The white oxide — actually very pale yellow when prepared in the laboratory — is the lead II monoxide PbO, an orthorhombic dimorph sometimes called 'massicot'. The orange form is either the lead II monoxide tetragonal dimorph, for which the term litharge is properly reserved (and is sometimes also called 'red lead'). Or it could be the tetroxide Pb_3O_4 (or $2PbO.PbO_2$) sometimes called 'minium', which also takes a tetragonal form.

Neither oxide commonly occurs in nature. However, lead II oxide is the intermediary in the production of lead from sulphide-bearing ores and lead tetroxide is formed by the calcination of lead II oxide at a temperature of *c.* 450° C. Consequently it is not hard to see how both oxides could be present in the labyrinth and how, given that lead oxides are poorly soluble in water, there could be a slow accumulation on the walls by leeching.

Lead oxides are, however, soluble in stomach hydrochloric acid, whence they are highly toxic. The white lead oxide soot from the smelters poisoned a great deal of farmland, many livestock and even people when it was carried away in watercourses, so do take appropriate precautions when handling it.

Although stable lead compounds typically have poor solubility in water it seems hard to believe that plants could survive in this toxic environment. But it is as a direct consequence of the contamination that smelter sites have been colonised by extremely rare, heavy-metal tolerant plants, which are additionally protected from grazing. Until recently there was an embargo on producing food for human consumption in areas around the mines and smelters, as lead can bioaccumulate in plants.

The last revival

To complete your tour, at Blackmoor there is a ruin of an ore washing building complete with a fragment of brick flooring containing a half round drainage channel.

By the 1870s falling metal values and low returns were taking their toll on mine profits and the venture could only be kept in operation with bail outs from share holders. This was not helped by the fact that Mendip lead is not very malleable and is often termed 'hard lead'. This made it a poor cousin to imported lead, though it was popular for bullets and shot. After the mid-19th-century revival, when 300 were employed the Charterhouse mine, it finally closed in 1885.

Conclusion

The Charterhouse site is more extensive than described here, for it stretches about another kilometre below the road embankment, through an area known as Velvet Bottom. Yet another reprocessing smelter had been built here. The full extent of the Charterhouse mine works can be seen on Google Earth. The Roman settlement can be seen, along with the run of three buddles by the road embankment and two of the five runs in Velvet Bottom.

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Book review

Mervyn Dodd, with a contribution by Maureen Fisher 2010 *The Story of Iron Ore Mining in West Cumbria*. Cumberland Geological Society (ISBN 978-0-95584-531-4; paperback, 82pp, £7.50)

This slim volume is packed with geological, mineralogical and historical information. It is a record of the history of mining in West Cumbria and of the individual mines in the area.

The last iron ore mine in Cumbria ceased production in 2008 after four centuries of mining, including a mining boom in the 19th century, when 10,000 people lived in and around Cleator Moor.

It is almost, but not quite, a field guide. The excellent maps point the visitor to the former mining locations. The simple, but clear diagrams show how the ore was emplaced. The numerous photographs, both colour and black and white, illustrate beautifully the boom times of the industry and the present-day sad decline of the area.

Mervyn Dodd (former President of the CGS and a retired deputy head teacher) has lived and worked in the area for 50 years and knows the Cumbrian geology intimately. His co-author, Maureen Fisher has a particular interest in oral history and has contributed a chapter on the lives of 'The Red Men', as there are still miners alive to recount their tales of working underground.

Mervyn Dodd is an OUGS member and years ago I was lucky enough to go on an OUGS field trip led by him to the West Cumbria ore-field. I greatly enjoyed revisiting Cumbria from my armchair. If you are going up that way, or have an interest in mining, buy or borrow a copy of this book.

— Mary Howie BA Hons (Open)

The 1730–1736 Timanfaya eruption on Lanzarote, Canary Islands: an introduction and guide to selected locations outside of the National Park

Duncan Woodcock (OUGS NW, duncan.woodcock@hotmail.co.uk)

Introduction

"Between nine and ten in the evening of 1st September 1730, at Timanfaya, two hours walk from Yaiza, the earth suddenly broke open. In the first night, a gigantic mountain reared up out of the lap of the earth, and from its peak flames leapt up and burnt incessantly for nineteen days. A few days later, a new chasm opened up and a river of lava poured out … and began flowing northwards, at the beginning as fast as water, but soon its speed slackened and it flowed as viscous as honey" (Editorial Yaiza 2007).

These are the opening words of an eyewitness account of the first two years of the eruption, recorded in the diary that was kept by Don Andres Lorenzo Curbelo, the priest of the village of Yaiza, Lanzarote at the time. The eruption was to continue for six years to become the largest historical eruption in the Canary Islands. The eruption resurfaced about a quarter of the island), destroyed a large part of the fertile land and forced the evacuation of most of Lanzarote's inhabitants (Fig. 1).

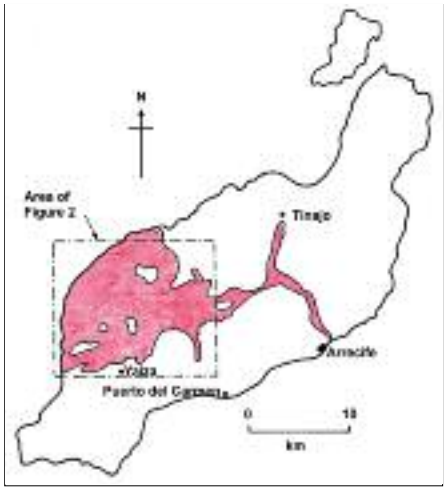

Figure 1 Sketch map of Lanzarote. Shaded area shows the extent of the 1730–36 Timanfaya eruption.

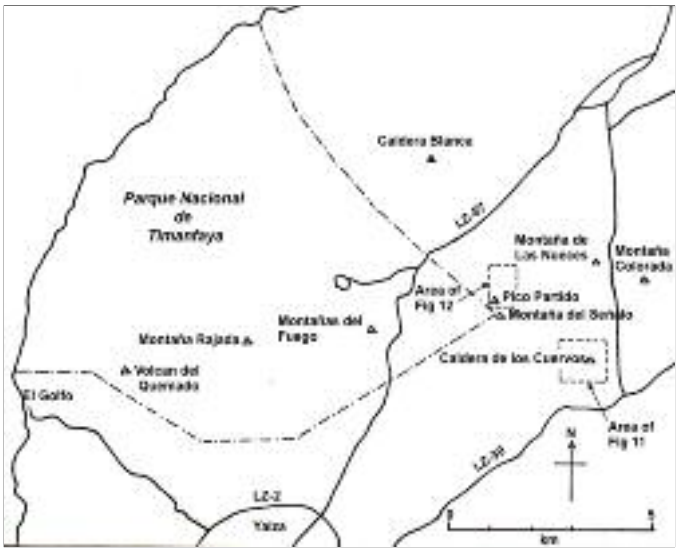

Figure 2 Location map for the main area of the Timanfaya eruption.

Progress of the eruption

A detailed reconstruction of the Timanfaya eruption was carried out in the early 1990s, based on the integration of detailed fieldwork with an examination of eyewitness accounts of the eruption (Carracedo *et al.* 1990; Carracedo and Badiola 1991). This paper draws on a summary of the reconstruction presented by Carracedo and Badiola (1992). The eruption progressed through a number of phases, distinguished by differences in vent location, eruption type and magma composition. Figure 2 provides an overview map of the area of the eruption and shows locations mentioned in the paper.

The initial phase of the eruption, from September 1730 to February 1731, produced the volcanic edifices of Caldera de Los Cuervos (Fig. 3) and Pico Partido (Fig. 4). The lavas produced were fluid, silica undersaturated alkali basalts that flowed northwest to the coast and south towards Yaiza. These lavas contain ultramafic inclusions that are locally abundant and of considerable size (Fig. 5, *overleaf*). The eruption continued from March to June at a new location, where it developed Montaña del Señalo

Figure 3 Caldera de Los Cuervos, viewed from the east.

Figure 4 The volcanic edifice of Pico Partido, viewed from the northeast with the upper 'lava lake' in the foreground.

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Figure 5 A selection of ultramafic inclusions from 'Olivine Col' (Fig. 12), Pico Partido area.

and produced alkali basalts that were substantially free of ultramafic inclusions.

At the end of June 1731, the location of the eruption suddenly moved *c.* 12km west, resulting in shallow submarine explosions just offshore. Activity then migrated east to produce the subaerial edifices of Volcan del Quemado, Montaña Rajada and Calderas Quemadas. These comprised clusters of scoria and spatter cones, together with alkali basalt lavas that flowed towards Yaiza.

From 1732 to early 1736 volcanic activity appears to have been concentrated in what is now the centre of the Timanfaya National Park. The island was largely evacuated at this time, so there are no surviving eyewitness accounts. The ongoing eruption continued to produce alkali basalts, and produced a complex of overlapping cones and lava flows known as the Montañas del Fuego.

The final phases of the eruption took place in March and April 1736. Activity shifted north-west to produce Montaña de Las Nueces and was accompanied by the eruption of a large tholeiitic flow field that extended south-east to the coast near the capital Arrecife, north as far as Tinajo and south-west in the direction of Puerto del Carmen (*see* Fig. 1). The distinctive pahoehoe flow field (Fig. 6) is described in detail by Solana *et al.* (2004). This penultimate phase of the eruption was followed by activity near by, which developed Montaña Colorada. The olivine tholeiitic lavas from this phase contain a wide variety of ultramafic, mafic and metasedimentary inclusions that are described in the following section.

Since the cessation of activity in 1736, Lanzarote has been volcanically dormant, apart from a small eruption in 1820. However, the area in the centre of the National Park appears to be hot, with temperatures up to 600°C at 10m depth (Carracedo and Day 2002).

Petrography

Table 1 (*opposite*) summarises petrographic details of selected basalts from the Timanfaya eruption. These basalts are grey, variably vesicular and aphyric in hand specimen. In thin section, most samples have a fine-grained groundmass that contains euhedral to anhedral crystals of olivine.

All the basalts studied, except those from the Nueces flow field, contain inclusions. Ultramafic inclusions of coarse-grained olivine are the most common inclusion. These are typically 1–10mm in size but occasionally much larger (Fig. 7). Mafic

Figure 6 A typical view over the Nueces lava flow field. Note the ropy pahoehoe flows and the inflation tumulus (bottom left).

inclusions are less common, but are present in the Pico Partido and Colorada lavas (Fig. 8).

Metasedimentary inclusions appear to be restricted to the Colorada lavas. These are typically 5–20mm, white or buff coloured angular fragments, most commonly with a very fine-grained texture, like broken porcelain (Fig. 9, *opposite*). Some metasedimentary inclusions contain small angular quartz grains, which suggest a sedimentary origin for these inclusions.

The metasedimentary inclusions have been studied in detail by Araña and Bustillo (1992) and by Aparicio *et al.* (2006). The inclusions have siliceous or calc-silicate compositions, produced by the thermal metamorphism of sedimentary rocks that were

Figure 7 (right) Ultramafic inclusions, Caldera de Los Cuervos.

Figure 8 (below) Mafic inclusion. Montaña Colorada.

Table 1 Petrographic details of selected basalts from the Timanfaya eruption

stage of eruption	*hand specimen observations*	*thin section observations*
Caldera de Los Cuervos	medium to dark grey, aphyric, fine-grained basalt with variable vesicularity	fine-grained groundmass enclosing crys tals of olivine, generally with irregular (resorbed?) margins
	often contains inclusions of crystalline, light-green, coarse-grained ferromagnesian minerals; inclusions typically 1–10mm in size, but occasionally much larger	peridotitic inclusions comprising olivine and orthopyroxene (opx); opx grains show reaction (?) fringes where in con tact with host basalt
Pico Partido	host basalt and light green inclusions as above	as above
	occasional white crystalline inclusions, typically 1–10mm in size, with speckling of a green, stubby mineral with at least one cleavage	gabbroic inclusions comprising plagio-clase and clinopyroxene (cpx) with minor olivine
Montaña de Las Nueces	medium-grey and aphyric; variably vesicular	coarser-grained than basalts from earlier stages; olivine and tabular plagioclase conspicuous; opaques in small irregular patches and 'needles'; high-relief grains too small to resolve (cpx?)
Montaña Colorada	medium-grey, variably vesicular, very fine-grained basalt; aphyric, but with abundant inclusions of various types:	fine-grained groundmass enclosing crystals of olivine; some euhedral, others with irregular (resorbed?) margins
	• ultramafic inclusions typically 1–10mm in size, but occasionally much larger; coarse–grained ferromagnesian minerals including pale green, glassy olivine and darker green or brown pyroxene	generally peridotites, with fresh olivine and subordinate opx; occasional dark brown translucent grain that shows isotropic behaviour between crossed polars — probably chromite
	• mafic inclusions typically 20–50mm in size; medium to coarse grained; white with a sprinkling of green, stubby mineral grains *c.* 1mm long with at least one cleavage; occasional pale green, glassy olivine grain	gabbroic inclusions comprising plagio clase and clinopyroxene (cpx) with minor olivine
	• metasedimentary inclusions	very fine-grained material has a uniform
	white or buff coloured, angular and 5–20mm in size; the most common type has a very fine-grained texture like broken porcelain; less common inclusions are coarser grained, looking like altered fine grained sandstones	or 'clotted' texture that occasionally contains distinctive circular area *c.* 0.1mm in diameter; coarser-grained inclusions contain variable amounts of small angular quartz grains

Figure 9 Metasedimentary inclusion, diameter c. *20mm Montaña Colorada.*

originally ocean floor sediments. Similar, unmetamorphosed sediments are exposed within the Basal Complex of Fuerteventura (Carracedo *et al.* 2002).

Occasionally, the finer-grained metasedimentary inclusions contain distinctive circular areas about 0.1mm in diameter. In most cases it is difficult to resolve any internal details: Figure 10 shows a sketch of the rather hazy details from one of the clearer examples. Similar features observed by Bustillo *et al.* (1994) have been interpreted as radiolarian fossils.

Figure 10 Sketch of possible radiolarian (diameter 0.2mm) in metasedimentary inclusion, Montaña Colorada.

Selected field locations

Much of the area covered by the eruption is contained within the Timanfaya National Park, where access is strictly limited to a short coach tour. However, some areas of volcanological interest escaped inclusion and can be appreciated close up rather than from the confines of the coach. The field guide by Greensmith (2000) describes the park coach tour itinerary, while the more recent field guide by Carracedo and Day (2002) contains brief details of several locations outside of the National Park.

This section provides details of two outstanding localities where many of the volcanological features of the Timanfaya eruption can be studied. Much of the description is presented on annotated field maps, which should be largely self-explanatory.

Caldera de Los Cuervos (Fig. 11) can be reached by a short walk from the road. The interior of the edifice is easily accessible and contains exposures of spectacular ultramafic inclusions (*see* Fig. 7).

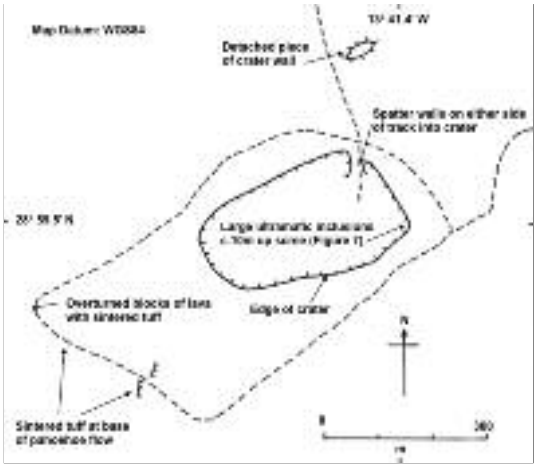

Figure 11 Field map of the area around Caldera de Los Cuervos.

The area around Pico Partido (Fig. 12) is a little more difficult to access, but the variety of volcanic features on display make the extra effort worthwhile. One can easily spend a whole day studying the area, which contains a well-exposed lava tube (Fig. 13), two perched lava 'lakes' (*see* Fig. 4) and several spatter mounds (Fig. 14, *opposite*). The features of a channelled lava flow and the significance of the 'superelevation' features (Fig. 15, *opposite*) are discussed in detail in Woodcock (2003) and in Woodcock and Harris (2006).

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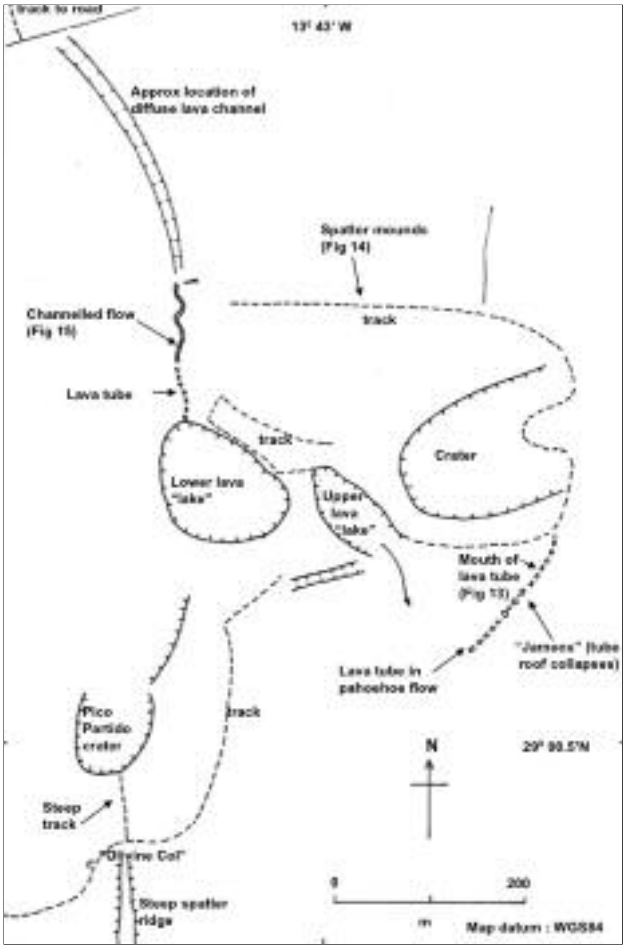

Figure 12 Field map of the area around Pico Partido.

*Figure 13 Lava tube with entrance surmounted by a small spatter mound. Pico Partido area (*see *Fig. 12 for location).*

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*Figure 14 Spatter mound. Pico Partido area (*see *Fig. 12 for location).*

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*Figure 15 Channelled lava flow showing well developed 'superelevation' features, Pico Partido area (*see *Fig. 12 for location).*

The Open University Geological Society Symposium 2010, Swansea

(held 9–11 July 2010 at the University of Wales, Swanea)

Editor's note

It is with great regret that, despite several attempts to request and persuade speakers at the OUGS Swansea Symposium 2010 to write-up their talks for the OUGSJ*, unfortunately neither the Editor nor members of the Swansea Symposium Planning Committee were able to do so. The speakers all have numerous academic commitments and were unable to write-up their papers for a variety of reasons.*

Therefore, for the benefit of the Symposium delegates and for those OUGS members who could not attend the Symposium, the abstracts are printed in this volume, in keeping with OUGS's new policy regarding Symposium lecture publication.

Using the climate of the past to improve predictions of the climate of the future

Prof. Danny McCarroll
School of the Environment and Society, University of Wales, Swansea

There is no remaining doubt that the climate of the Earth is changing, and that humans are responsible. Predictions of the future evolution of climate, however, remain uncertain, even given a single scenario for future greenhouse gas emissions. The central problem is that we do not know the sensitivity of the climate system to increases in atmospheric carbon dioxide. Far a doubling of CO_2 above pre-industrial levels, the eventual increase in mean global temperature is estimated to be between 2˚ and 4.5˚C. Warming over land is likely to be about double the global average, soothe range of uncertainty is huge, ad despite the best efforts of climate modelers as not improved appreciably over the last 30 years.

Reconstructions of the climate of the past could be used to reduce the uncertainty if combined with perturbed physics ensembles of climate models. In a perturbed physics ensemble the uncertain parameters of the model, such as those that control cloud parameters, are changed within a reasonable range. Each model variant can be given a likelihood score on the basis of how well it reconstructs the climate of the past, and those scores can be applied to the future climate that each model variant predicts. As well as instrumental and documentary sources, there are many natural archives from which palaeoclimate information can be gleaned, including tree rings, lake sediments, peat mires and ice cores. Some new palaeoclimate reconstructions for different regions of Europe [were] presented and compared with the preliminary results of a perturbed physics ensemble run by climateprediction.net using the UK Meteorological Office FAMOUS model.

The first Late Quaternary diatom silica Oxygen isotope records from the Atlantic margin

Jennifer Pike[1], Melanie J. Leng[2], George E. A. Swann[2] and Andrea Snelling[2]
[1] School of Earth and Ocean Sciences, Cardiff University
[2] NERC Isotope Geoscience Laboratory, British Geological Survey

Antarctica and its ice sheets have played, and continue to play, a major role in the global ocean-atmosphere system; hence, it is crucial that we have a sound understanding of the past behaviour of Antarctica and its ice sheets with a view to understanding their variability under a warming climate. Ice cores and ocean sediments provide intriguing insights into the timing and nature of the rapid climate transition that occurred at the last deglaciation (~13–11kyr BP) and the Southern Ocean is key to mechanisms proposed for the bipolar seesaw of global thermohaline circulation that drives such inter-glacial cycles and rapid climate transitions. In order to further investigate these processes that originate in Antarctica and lead to changes in global climatic conditions it is necessary to understand the transfer mechanisms of ocean-climate signals from the Antarctic ice sheets, across the continental margin, into the Southern Ocean.

The environment of the Antarctic continental margin is dominated by the seasonal advance and retreat of the sea ice. As such, the seasonal variability in sea ice coverage around Antarctica is one of the most significant factors regulating the energy balance of the Southern Hemisphere's atmosphere and oceans.

Exceptional, high-resolution Antarctic margin sediment cores recovered during the last decade contain an excellent archive of these ice-ocean-climate interactions, often on seasonal timescales, from the last deglaciation and throughout the Holocene. Indeed, many of these cores from the continental shelf contain exceptionally well-preserved laminated sequences through the last deglaciation and partially laminated sequences through the Holocene. These laminations are dominated by exceptionally well-preserved fossil planktonic diatom assemblages, individual species of which are sensitive to sea surface conditions, including sea ice concentration, fresh-water influx, and open ocean influence on the margin. The deglacial laminations have been shown to be seasonal in origin, with spring laminae dominated by diatoms associated with the spring sea ice melt and the formation of a freshwater cap trapping nutrients in the surface waters (e.g. *Hyalochaete Chaetoceros* spp.); summer laminae associated with diatoms that favour slightly more oligotrophic, open-water conditions (e.g. *Corethron criphilum* and *Rhizosolenia antennata*); and autumn laminations associated

with diatoms that form resting spores in response to lowering light levels and sea ice re-advance (e.g. *Thalassiosira antarctica*). We intend to anlayse the $\delta^{18}O_{diatom}$ record from the deglacial and Holocene Antarctic sediments in order to investigate proposed mechanisms of formation for the deglacial laminated unit. Further, because the deglacial laminations contain diatom assemblages/species related to specific seasons, we hope to construct $\delta^{18}O_{diatom}$ records through the Holocene to look at the long-term evolution of seasonality.

The first results of this research [were] presented.

The cutting edges of early mammal research: investigating the ecology of two of the first mammals from the fissure fills of Glamorganshire

Dr Pamela G. Gill
University of Bristol

Triassic-Jurassic fissure fills from Glamorganshire, Wales, UK, offer a unique window into the evolution of Mesozoic mammals. Two of the first mammals, *Morganucodon* and *Kuehneotherium*, lived here on a small limestone island and their remains were swept into caves and fissures, now revealed by quarrying. Although the bones are fragmented, the abundance of material offers a rare opportunity to study population variation and individuals at varying growth stages. New imaging techniques and computer software provide insights into the jaw and dentition of these early mammals.

Two distinct faunas are found on the island: one with a wealth of reptilian taxa co-existing with the two early mammals, and one apparently depauperate [an ecosystem lacking in numbers or variety of species] with only three small insectivorous tetrapods. Several suggestions have been made for this [situation], including selective predator selection, but a detailed quantitative analysis of the molars of the two mammalian taxa reveals unexpected taxonomic diversity in the mammals, with the molars clustering in morphospace relative to locality. This [evidence] suggests a temporal difference for the fissure infills. Whether this [difference] is related to the decreasing size of the island or [to] wider environmental changes at the end of the Triassic is more difficult to decide.

We further investigated the Mammalian ecological diversity, employing finite element analysis (FEA) and tooth microwear analysis. High-definition synchrotron radiation XμCT (SRXTM) was used to generate a 3D virtual jaw for each taxon and a comparative study of lower jaw functional morphology was carried out. We conclude that *Morganucodon* fed on 'hard-object' prey, whereas *Kuehneotherium* was specialized for rapid, snapping jaw closure and [for] consuming more malleable foodstuffs, thereby indicating early ecological diversity within basal mammals.

Interpreting the Earth's oldest rocks

Prof. Julian Pearce
University of Wales, Cardiff

Development of plate tectonics on a planet is probably a necessary condition for the evolution of intelligent life. Clearly, the Earth has both plate tectonics and intelligent life; it may be no coincidence that Venus, a planet of similar mass and volume has no plate tectonics and no life. But has the Earth always lost its heat by plate tectonic processes ort is this a more recent phenomenon? And why did plate tectonics start on Earth? My contribution to this debate is to study the most ancient volcanic rocks for geochemical signatures indicative of subduction, the driving force of plate tectonics.

At the present day, subduction-related rocks from volcanic arcs have a distinctive geochemical pattern resulting from the distillation of selected elements (the subduction-mobile elements) from the subducting plate. In the Archean, however, these signatures are not always easy to determine. The best record of Archean volcanism can be found in the Pilbara of Western Australia, with [more than] 800Ma of (episodic) volcanic activity.

Using new methods of geochemical fingerprinting developed in Cardiff, it is possible to demonstrate that most of these rocks were not influenced by subduction: they represent magma derived from mantle plumes and contaminated by continental crust during ascent to the surface. Only at about 3,100Ma do we find rocks with apparent subduction signatures. Elsewhere, notably in South Africa and Canada, subduction signatures appear only late in the Archean volcanic record, thus suggesting that the Earth may have evolved for about one-third of its history before plate tectonics began. This [conclusion] is disputed, however, by many scientists, with reference to two key areas: Isua in Greenland, which contains the Earth's oldest rocks at *c.* 3,800Ma; and Jack Hills in Western Australia, which contains the Earth's oldest minerals, namely zircons within clastic sediments at *c.* 4,400Ma.

In this presentation, I [examined] critically the evidence for subduction in these materials and [concluded] that the Earth may have taken some time to develop a form of plate tectonics and longer still to develop plate tectonics of the type seen at the present [time].

Tracing volcanic events in the Greenland ice cores

Dr Siwan M. Davies
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Polar ice cores provide an unprecedented insight into the nature, timing and rate of climatic changes during the Late Quaternary. In particular, evidence from the Greenland ice cores revolutionized our understanding of past climate by demonstrating that the glacial period was characterised by rapid and abrupt climatic events. Not only do theses sequences offer high-resolution climatic reconstructions, they also represent valuable archives for developing a framework of past volcanic events. The high temporal resolution, detailed chemostratigraphy and well-constrained age models present an ideal opportunity for the identification of tephra horizons.

Here we report on the ongoing work on the Greenland ice cores (NGRIP, GRIP and NEEM) to construct a framework of volcanic events for the last interglacial and the ensuing glacial period — a time interval during which the volcanic history is poorly understood. This framework comprises independent ice core age estimates for each tephra horizon, as well as [for] trace element geochemistry. A number of previously known volcanic events are detected, adding to our knowledge of volcanism in the North Atlantic region, and also farther afield.

Furthermore, two examples are presented to highlight how this framework can be utilised for the precise correlation of palaeoclimatic archives in order to test the synchoneity of rapid climate events in the North Atlantic region.

Natural blowouts in sedimentary basins: evidence for highly focused fluid flow from 3D seismic data

Prof. Joe Cartwright
3DLab, School of Earth, Ocean and Planetary Sciences, Cardiff University

Subsurface fluid pressures are only very rarely known to approach the present-day lithostatic gradient, but evidence [was] presented here that supralithostatic fluid pressures have existed in many sedimentary basins in the past. The evidence comes from two sources: (1) the widespread occurence of [the] development of sandstone intrusions with a sill-like geometry; and (2) fluid expulsion pipes ascending >1km from synclinal regions and homoclinially dipping slopes.

The sandstone sills can be up to 2km in diameter and >100m thick, and form interconnected networks ascending [more than] 1,000m through ultra-fine 'sealing' sequences. It is argued here from the classical mechanics of sheet intrusions that sandstone sills of this scale can only be sources from a pressure compartment (with a major net sand component) that has pore fluid pressure in excess of lithostatic.

The fluid expulsion pipes are typically 50–100m in diameter, with cylindrical geometry and with circular to elliptical appearance on slice imagery [i.e. in section]. They can be >2,000m tall, and are associated with hydrocarbon anomalies on seismic data. They feed surface or palaeo-pockmark craters, indicating [that] a significant fluid flux was in transit along the pipes, either during their formation or over subsequent periods. From an analogy with igneous diatremes, it is argued that these pipes are also expressions of rapid fluid release from supralithostatic pressure compartments.

These examples of natural 'blowouts' are not isolated phenomena: their distribution is at the basin scale, and they are found in many different basins, from passive continental margins to active subduction-related basins. The hydrodynamics of both processes [were] discussed, and a case [made] for their genesis. Mechanisms that can bring source regions driving the processes of emplacement of these extraordinary features [were] suggested to be major earthquake, rapid erosional unloading and bolide impacts.

A new view of seafloor spreading at the Mid-Atlantic Ridge

Prof. Chris MacLeod
School of Earth and Ocean Sciences, Cardiff University

Seafloor spreading, the process by which new volcanic ocean floor is created at mid-ocean ridges, generates 60% of the surface of the planet and is arguably the most fundamental geological process on Earth. As the plates are pulled apart hot, ductile mantle beneath is drawn upward, decompresses and partially melts, rising to form a6–7km thick igneous ocean crust. This supposedly simple 'conveyor belt' model has graced textbooks since the advent of the plate tectonics paradigm in the 1960s.

However, the recovery of samples of serpentinite — altered mantle rock — from the seafloor at some ridge axes requires us to re-examine the basic seafloor-spreading paradigm. Why is the Earth's crust missing? Did it never form, or has it been ripped away? I present[ed] results from recent cruises to the Mid-Atlantic Ridge during which we attempt[ed] to solve this conundrum using a variety of tools both modern and ancient.

The South Wales coalfield: geology, landscape evolution and some post-industrial geo-environmental issues

Dr Peter Brabham
School of Earth and Ocean Sciences, Cardiff University

This lecture [looked] at the geological and landscape evolution of the South Wales coalfield. In particular it [explored] the relationships of geological stratigraphy, structure ad geomorphology that have influenced the industrial development of the coalfield. The coalfield can be broken down into at least five distinct zones: the eastern iron zone, the south-western metallurgical smelting belt, the north-western anthracite belt, the central steam coal area and the south crop mining area. Each of these zones [has] a distinct geological / geomorphological control and industrial history. At the peak of the mining industry in 1913 there were [more than] 1,000 large coal mines in South Wales, with Cardiff the busiest export port in the world. The last deep coal mine, Tower Colliery, closed in January 2008 and coal is only mined today for power stations at a few opencast mines, some of which are linked to land regeneration schemes.

In this modern post-industrial era, the long legacy of natural resource exploitation has left behind plenty of work for the modern geoscientist. The talk [explored] some of these legacies, which include old mine workings, landslides, acid mine drainage and large areas of contaminated land. Current research projects at Cardiff University to help tackle some of these post-industrial issues found in South Wales [were] described. Modern 3D landscape visualsation techniques [were] used to look at some of these old problems in a new light and show how the valleys are gradually changing their identity again.

The Severn Barrage: potential hydro-environmental impact on the Severn Estuary

Dr William Rauen
Hydro-environmental Research Centre, School of Engineering, Cardiff University

In recent years there has been growing international concern about climate change, CO_2 levels, increasing oil prices, etc. These issues have led to renewed enthusiasm to consider proceeding with a barrage, either in the original location proposed by the Severn Tidal Power Group (STPG) or at a smaller scale, such as ther Shoots Barrage. In particular, the Sustainable Development Commission concluded in itsx 2007 report that "Electricity from a barrage would make a significant contribution to the UK's renewable energy targets." As well as the Severn Barrage there is considerable scope for various forms of tidal energy along the Severn Estuary, as well as [on] the North Wales coast.

The presentation [reviewed] the current main Severn Barrage [proposal] as originally promoted by STPG, together with giving a brief overview of alternative options such as the Shoots Barrage and Offshore Tidal Impoundments. In particular, emphasis will focus on assessing the potential hydro-environmental impact of a barrage, including the implications for geomorphological- and flood-risk changes. Finally, an outline [was] given of recent research undertaken by the Hydro-environmental Research Centre on bacterial–sediment interactions and the application of computational hydro-environmental models to predict the impacts of a barrage on tidal currents, [on] sediment transport concentrations and [on] the background bacterial levels. The presentation [showed] that the [Severn] Barrage has the potential to reduce the tidal currents in a highly dynamic estuary, leading to reduced suspended sediment loads, increased light penetration within the water column and, potentially, an increase in the benthic bio-diversity in the [Severn] Estuary.

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